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TAPHONOMY OF THREE MONOSPECIFIC DINOSAUR BONE BEDS
IN THE LATE CRETACEOUS TWO MEDICINE FORMATION,
NORTHWESTERN MONTANA: EVIDENCE FOR DINOSAUR MASS MORTALITY
RELATED TO EPISODIC DROUGHT

by

Raymond R. Rogers

B.S. Northern Arizona University, 1985

Presented in partial fulfillment of the requirements
for the degree
Master of Science
University of Montana
1989

Approved by:

John R Horner
Co-Chairman, Board of Examiners

Co-Chairman, Board of Examiners

Dean, Graduate School

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Rogers, Raymond R., M.S., June 1989 Geology

Taphonomy of Three Monospecific Dinosaur Bone Beds in the Late Cretaceous Two Medicine Formation, Northwestern Montana: Evidence for Dinosaur Mass Mortality Related to Episodic Drought (102 pp.)

Directors: John R. Horner JRH
Donald Winston DW

Monospecific and "single-species dominated" dinosaur bone beds are relatively common within the alluvial sediments of the Late Cretaceous (Campanian) Two Medicine Formation of northwestern Montana. Taphonomic analysis of three monospecific dinosaur bone beds in the upper lithofacies of the formation suggests dinosaur mass mortality related to episodic drought. Two of the bone beds, Canyon Bone Bed and Dino Ridge Quarry, preserve the remains of an as yet undescribed species of Styracosaurus. The third bone bed, Westside Quarry, preserves skeletal remains of undescribed prosauralophan hadrosaurs. Taphonomic and geologic data indicate that all three dinosaur quarries are autochthonous, non-catastrophic mass mortality fossil assemblages. The styracosaurs in Canyon Bone Bed and Dino Ridge Quarry are buried in shallow, vegetated oxbow lake paleoenvironments. The prosauralophan hadrosaurs of Westside Quarry are interred within and around what may have been an ephemeral floodplain water hole. Paleoclimatic data suggest that the Two Medicine coastal plain was affected by a seasonal, semiarid, and warm climate during the latest Campanian. Each of the three bone beds is stratigraphically associated with sediments reflecting abnormally dry conditions, and I propose that episodic regional drought, and resultant malnutrition and disease, lead to the mass mortality events responsible for all three bone beds.

Assuming a genetic relationship between drought and the three bone beds, certain autecologic inferences can be drawn. The styracosaurs preserved within Canyon Bone Bed and Dino Ridge Quarry and the prosauralophan hadrosaurs of Westside Quarry may have been water-dependent species. During periods of drought, these particular dinosaurs may have had to remain close to perennial water sources. The monospecific nature of the quarries suggests that the dinosaur species under investigation were probably social, herding animals during periods of water-stress, possibly year-round. Partitioning of dry season resources by dinosaurs on the Two Medicine coastal plain, trophic dynamics, and interspecific aggression and territorial behavior are all possible motives behind the monospecific character of the three bone beds.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to the members of my thesis committee: Dr. John R. Horner, Dr. Donald Winston, Dr. Robert W. Fields, and Dr. Kerry Foresman. Their insight, encouragement, and editorial assistance are greatly appreciated. I would especially like to thank Jack Horner for the opportunity to work on his three bone beds. I also extend thanks to Pat Leiggi, Ken Carpenter, and the late Robert Makela for invaluable conversations and ideas. Robert Makela also graciously shared his time and knowledge familiarizing me with collecting dinosaurs. Dr. Greg Retallack provided assistance in understanding and interpreting paleosols, and Ed Brook, John Kruger, Pat Reynolds, and Kirsty Erickson all furnished help in the field. I am very grateful to Ricky Reagan and Gloria Sundquist for allowing access to their ranches. I would also like to thank Dr. James Sears, Dr. David Alt, and Scott Sampson for helpful discussions, and John Cuplin for assistance with my graphics. Lastly, I would like to thank the M.O.R. field crews; without their help none of this would have been possible.

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PART ONE--INTRODUCTION

Monospecific vertebrate bone beds are unusual in the geologic record. The fundamental and obvious requisite of a monospecific bone bed is the mass death of animals of the same species. One way in which numerous individuals of a single species may end up in the same mass grave is by a sudden catastrophic event that rapidly kills all or part of a monospecific herd or gathering of animals. This process is classified as catastrophic mass mortality by Carpenter (1988). A second way in which the bones of a single species of animal may be buried together is by the death of many individuals of the same species over time in a limited area (for example, mortality during drought). Carpenter called this process noncatastrophic mass mortality. Monospecific mass death assemblages that are not immediately buried must be interred soon after death in order to minimize the effects of subaerial weathering, transport, scavenging, trampling, and attritional input (Voorhies, 1969; Behrensmeyer, 1978; Haynes, 1980; Gifford, 1985; Carpenter, 1989). If sedimentation rates are adequate and burial does ensue, preservation of the deposit is still not assured. The chemical characteristics and stability of the enclosing sedimentary matrix, as well as any subsequent pedogenic, diagenetic, or metamorphic effects, ultimately determine if preservation and fossilization are to occur (Hare, 1980; Gordon and Buikstra, 1981; White and Hannus, 1983; Retallack, 1985). Finally, present day erosion must uncover, but not destroy the deposit.

Despite the necessary sequence of events, monospecific fossil bone beds are occasionally discovered. The taphonomy of a monospecific titanothere assemblage in the Washakie Basin of southwestern Wyoming was investigated by Turnbull and Martill (1988), and a very bizarre monospecific bone bed in Brazil containing an estimated 40,000 side-necked turtles was reported by Wood (1988). An extensive monospecific bone bed in the Early Cretaceous Twin Mountains Formation of Texas that preserves the remains of numerous hypsilophodontid dinosaurs was described by Winkler and others (1988), and monospecific ceratopsian bone beds in the Late Cretaceous sediments of Dinosaur Provincial Park in Alberta, Canada were described by Sternberg (1970), Currie (1981), and Wood, Thomas, and Visser (1988). However, most of the bone beds in Dinosaur Provincial Park contain disarticulated skeletal remains from numerous genera, and only five percent of all the dinosaur bone beds discovered within Dinosaur Provincial

Park can be classified as "low diversity" (Koster and Currie, 1987; Wood, Thomas and Visser, 1988).

In contrast with most vertebrate-bearing formations, several monospecific dinosaur bone beds have been discovered within the Late Cretaceous Two Medicine Formation of northwestern Montana. In fact, most of the Two Medicine bone beds are monospecific, or heavily biased toward single species domination.

The Two Medicine Formation as a whole contains an incredibly abundant and diverse vertebrate fauna. The known Two Medicine dinosaur assemblage includes the genera *Albertosaurus*, *Troödon*, *Corythosaurus*, *Leptoceratops*, *Monoclonius*, *Centrosaurus*, *Styracosaurus*, *Edmontia*, *Dyoplosaurus*, *Maiasaura*, *Orodromeus*, and *Stegoceras*, as well as an ornithomimid, a dromaeosaurid, a prosauralophan hadrosaur, and a lambeosaurine hadrosaur (Horner, 1984; Horner and Weishampel, 1988). The non-dinosaurian vertebrate assemblage includes *Champsosaurus*, garpike, turtles, mammals, and small lizards. The first major paleontological collecting expeditions in the Two Medicine Formation were lead by C. W. Gilmore of the United States National Museum, Washington D.C., from 1913 to 1935 (Gilmore, 1914, 1917, 1922, 1929, 1930, 1937, 1939). Barnum Brown, of the American Museum of Natural History, New York, also guided expeditions in 1916, 1917, and 1938 (Horner, 1984). More recently, John R. Horner, from the Museum of the Rockies, Bozeman, Montana, has directed the paleontological excavations within the Two Medicine Formation. His discoveries have illuminated exciting aspects of dinosaur behavior, ecology, and physiology. He has discovered fossil sites that contain clues enabling him to interpret dinosaur nesting and herding habits and to propose that dinosaurs provided care for their young (Horner and Makela, 1979; Horner, 1982, 1984; Horner and Weishampel, 1988). Furthermore, Horner has discovered and collected numerous specimens of juvenile dinosaurs and dinosaur embryos, illustrating in detail the ontogeny of some dinosaur species (Horner, 1988).

During the summer field season of 1985, Horner discovered three extensive dinosaur bone beds within the Two Medicine Formation north of the town of Cut Bank, Montana. The three bone beds are: Canyon Bone Bed, Dino Ridge Quarry, and Westside Quarry. Canyon Bone Bed and Westside Quarry are monospecific, whereas Dino Ridge Quarry is very strongly dominated by a single species. Canyon Bone Bed contains the remains of at least seven individuals of an undescribed species of *Styracosaurus*; Westside Quarry contains the remains of at least five individuals of an undescribed species of prosauralophan hadrosaur. Fossilized skeletal elements of at least eight undescribed styracosaurs and two hadrosaurs were discovered in Dino Ridge Quarry.

I studied in detail the taphonomy and sedimentology of all three bone beds as excavation and collection proceeded. I also analyzed the local and regional sedimentology and stratigraphy in order to understand the local and regional paleoenvironments of the three bone beds.

Taphonomic and geologic data indicate that the animals in Dino Ridge Quarry, Canyon Bone Bed, and Westside Quarry are buried where they perished, and therefore these quarries preserve autochthonous mass mortality fossil assemblages. Paleoclimatic data suggest that this region was affected by a seasonal, semiarid, and warm climate during the latest Campanian. Each of the three bone beds is stratigraphically close to sediments reflecting abnormally dry conditions, and I propose that episodic, regional drought, and resultant malnutrition, disease, and possibly flooding intensified by denudation of the landscape and decreased infiltration due to caliche development (Shipman, 1975), lead to the mass mortality events responsible for all three bone beds.

Analysis of the geologic data and the taphonomic data from all three bone beds also provides insight into the autecology of the dinosaur species represented in the fossil assemblages. Providing that the three bone beds are indeed autochthonous, and that they are all genetically related to periodic episodes of drought, it follows that the ecological response to drought of the dinosaur species represented can be partially determined. The styracosaurs preserved within Dino Ridge Quarry and Canyon Bone Bed and the prosauralophan hadrosaurs of Westside Quarry may have been water-dependent species. During periods of drought, these particular dinosaurs may have had to remain close to water sources. Consequently, their bones are abundantly represented in and around the more persistent freshwater deposits in the upper lithofacies of the formation.

Landslide Butte field area--

The three bone beds under investigation occur in an isolated region of badlands along the drainage of the Milk River, in the vicinity of Landslide Butte, approximately 38 kilometers northwest of the town of Cut Bank, Montana (figure 1). The badland exposures encompass an area of roughly three square kilometers in sections 15, 16, 21, 22, 27, and 28, T. 37 N., R. 8 W. of the Landslide Butte Quadrangle. Dino Ridge Quarry and Westside Quarry are on the property of the Reagan Ranch; Canyon Bone Bed is on the property of the Sunquist Ranch. The surrounding badlands lie in Glacier County, within the boundaries of the Blackfeet Indian Reservation.

Most of the Two Medicine strata exposed in the Landslide Butte field area were deposited by streams and river systems. Tabular sheets of greyish-green overbank mudstone and thin, discontinuous lenses of cross-bedded channel

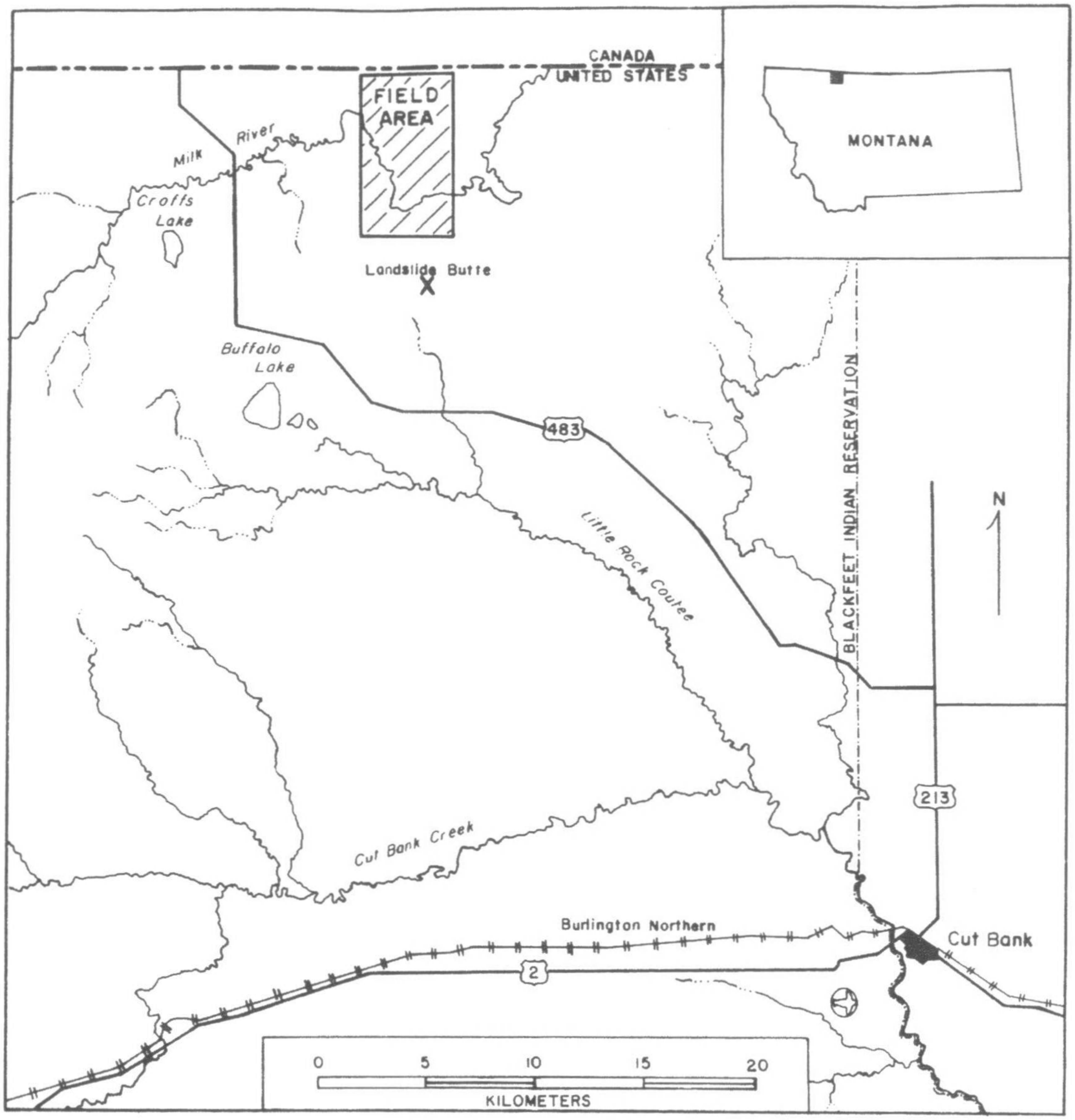


Figure 1--Location map of the Landslide Butte field area.

sandstone are common. Pedogenic carbonate horizons, shallow lacustrine and tiphic deposits, and volcanic ash layers occur as well. The excellent exposures afforded by the badland outcrops, the sparse vegetation on the badland slopes, and the nearly horizontal attitude of the Two Medicine strata in the region facilitated three-dimensional analysis of the rock facies.

Procedure--

Taphonomic data were collected from the three fossil assemblages. Detailed maps at a scale of 1:20 were plotted from a meter grid system for each bone bed; bones were removed from the quarries only after they were mapped in their exact positions and numbered. The trend and plunge of every elongate bone were measured with a Brunton Compass, and lower-hemisphere stereographic plots of bone trend and plunge data were constructed to graphically display the three-dimensional orientation of linear skeletal elements within the bone beds. Surface features of the bones were investigated both in the quarries and in the laboratory after preparation to define weathering conditions (local climate and soil chemistry), duration of subaerial exposure, and the extent of trampling and scavenger activity (Behrensmeyer, 1978; Behrensmeyer, Gordon, and Yanagi, 1986; Haynes, 1980). I examined all specimens following preparation in order to ascertain the minimum number of individuals represented in each assemblage, the taxonomic diversity of each assemblage, and the relative ages of members of the same species in each assemblage (adult, subadult, juvenile).

Sedimentologic data relevant to the taphonomy was collected from each bone bed as well. Petrographic and micromorphologic paleopedologic features of the bone bed matrices were determined from petrographic thin-sections. Clay mineralogies of the bone beds and the associated paleosol horizons were determined by X-Ray diffraction analysis. Macroscopic sedimentary structures and pedogenic features were described in outcrop and traced in order to determine the lateral and vertical extent of the bone bed horizons. A Munsell Color Chart was used to accurately and systematically describe the color of the bone bed sediments and to better define the contact between the bone bed horizons and surrounding sediments. Detailed stratigraphic sections were measured by Brunton Compass and Jacob's Staff through all three quarries so they could be placed in their respective stratigraphic positions. A laterally extensive bentonite horizon provided the datum necessary for stratigraphic control. The Munsell Color Chart aided in identifying and differentiating subtle hues of paleosol horizons within seemingly uniform stratigraphic units. Every divisible sedimentary unit was fully described in the field, and a small sample was collected from each stratigraphic unit for petrographic and clay mineral analysis.

PART TWO--TWO MEDICINE FORMATION

General geology--

The Late Cretaceous (Campanian) Two Medicine Formation, a foreland molasse deposit, crops out to the east of the Rocky Mountain Overthrust Belt in northwestern Montana. The formation attains a maximum thickness of about 600 meters, although thickness varies greatly. Two Medicine strata extend from the Montana Disturbed Belt, where they are faulted and folded, eastward to the relatively undeformed plains. The formation pinches out to the east against the western limb of the Sweetgrass Arch. Excellent exposures are scattered in drainages and along roadcuts from the town of Wolf Creek, Montana, northward to the international border (figure 2).

Stebinger (1914, 1916, 1917) originally described the Two Medicine type section, which is exposed along the drainage of the Two Medicine River in the southern part of the Blackfeet Indian Reservation. Cobban (1955) subsequently studied the formation in detail along with the other Cretaceous rocks of northwestern Montana. Characteristics of the southern, increasingly volcanic portion of the formation were investigated by Viele and Harris (1965) and Schmidt (1966). Tectonic, stratigraphic, and sedimentologic aspects of the Two Medicine Formation were comprehensively addressed by Lorenz (1981), and a generalized type section was published by Lorenz and Gavin (1984).

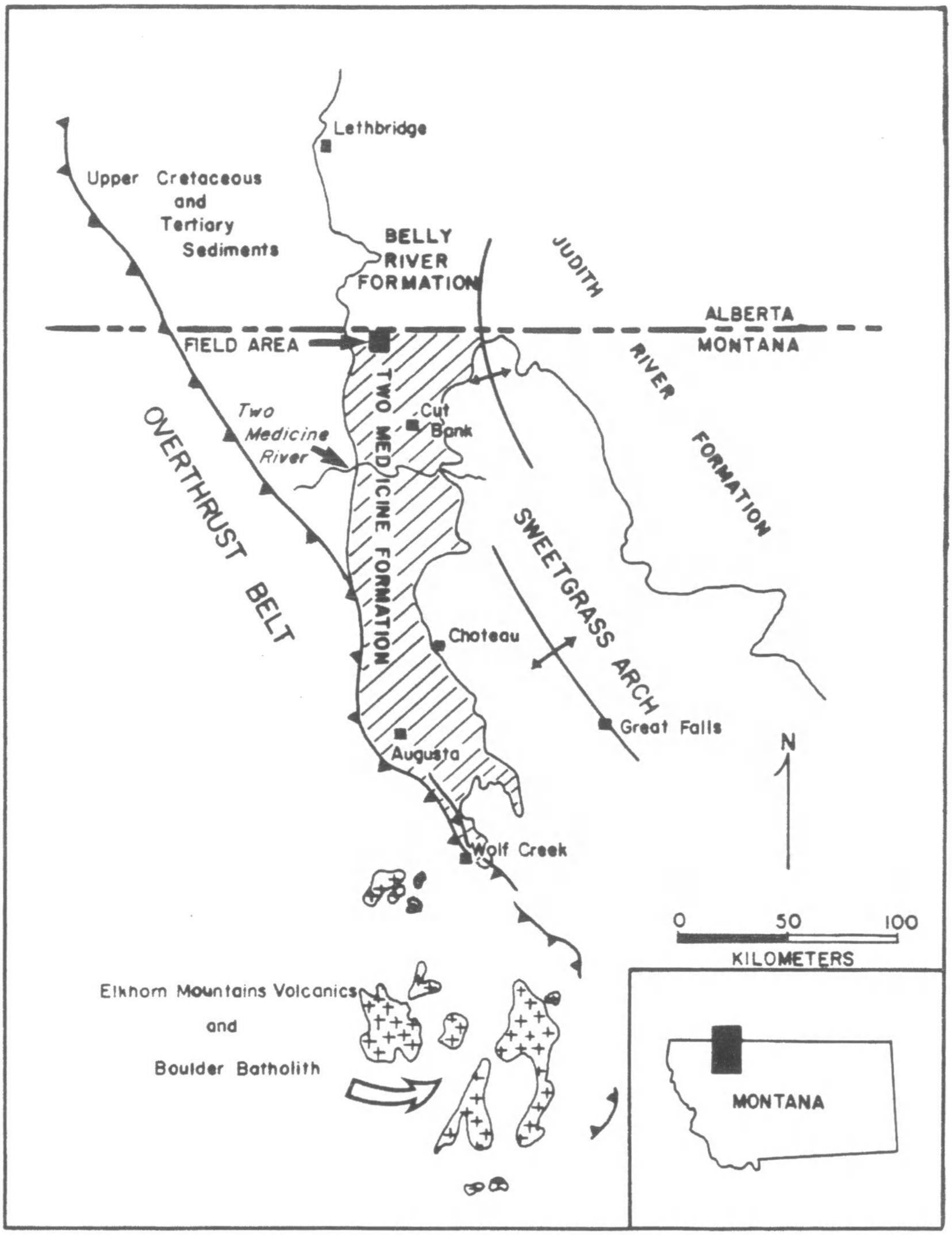


Figure 2--Generalized outcrop map of the Two Medicine Formation with associated geologic and geographic features (modified from Lorenz, 1981).

Gill and Cobban (1973) zoned the Two Medicine Formation on the basis of ammonites in correlative marine deposits and concluded that deposition occurred throughout most of the Campanian Stage. However, recent faunal discoveries may relegate the lowermost strata of the formation to the latest Santonian and redefine the uppermost Two Medicine strata as earliest Maastrichtian (Horner, pers. comm., 1988).

Correlative deposits on the eastern flank of the Sweetgrass Arch in Montana include the Eagle Sandstone, Claggett Shale, Parkman Sandstone, Judith River Formation, and Bearpaw Shale (figure 3). Canadian lithostratigraphic equivalents include the Belly River Formation, Bearpaw Formation, and lowermost Edmonton Formation, exposed in the southwestern foothills of Alberta, and the Milk River Sandstone, Pakowki Formation, Judith River Formation (Foremost Formation and Oldman Formation), and Bearpaw Formation, all of which are exposed further eastward in the plains of southern Alberta (Russell, 1970; Dodson, 1971; Koster et al., 1987).

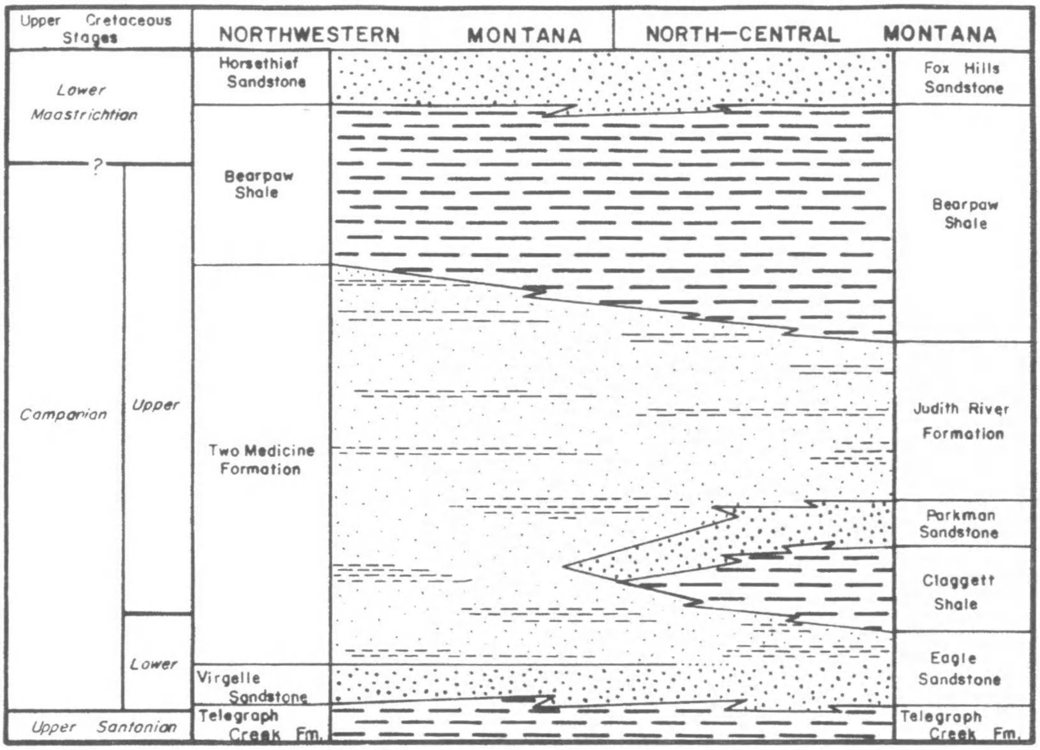


Figure 3--Montana Group stratigraphy in northwestern and north-central Montana.

Structural setting--

The Late Cretaceous Interior Seaway occupied the extensive retroarc foreland basin coupled to the foreland thrust belt of the North American Cordillera (Jordan, 1981). Within Montana, the various marine and nonmarine formations comprising the Montana Group were deposited in and adjacent to this epicontinental seaway. The Two Medicine Formation, included within the Montana Group, was deposited on the western shore of the Late Cretaceous Interior Seaway, between the eastward advancing margin of the overthrust belt and the oscillating western strand of the seaway. Terrigenous tectogenic sediments shed from the Cordilleran highlands to the west, and andesitic volcanoclastic debris eroded from the Elkhorn Mountains Volcanics, were deposited on the Two Medicine coastal plain by aggrading streams and river systems. Near the Elkhorn Mountains source area, latite and trachyte flows and rhyolitic welded tuffs intertongue with fluvially deposited Two Medicine sediments (Schmidt, 1966, 1972; Chadwick, 1981).

Sea-level fluctuations in the Late Cretaceous Interior Seaway greatly influenced the depositional history, stratigraphy, and sedimentology of the Two Medicine Formation. Horner (1984) suggested that the evolution of the Two Medicine dinosaur fauna was also influenced by transgressive-regressive cycles in the seaway. Most workers agree that tectonism in the North American Cordillera, as opposed to worldwide eustatic controls, produced these transgressive and regressive episodes (McLean and Jerzykiewicz, 1978; Gill and Cobban, 1973; Lorenz, 1981). Convergent tectonic activity, resulting in thrusting and mountain building, created (or increased) an isostatic imbalance in the crust. Rapid subsidence of the adjacent foreland basin coupled to the overthrust belt compensated for this imbalance, and rapid (possibly isochronous) transgression ensued. Subsequent erosion of the highlands, and input from volcanic source areas associated with the tectonism, supplied abundant detritus to the Two Medicine coastal plain, resulting in slow progradation of the shoreline and diachronous regression of the seaway strand. Deposition of the Two Medicine Formation commenced at the onset of the Eagle regressive phase and continued until maximum transgression of the Bearpaw Sea (Lorenz, 1981).

Stratigraphy and sedimentology--

The terrestrial sediments comprising the Two Medicine Formation form a westward and southward thickening clastic wedge. Accordingly, the upper contact of the formation is a diachronous boundary that climbs stratigraphically to the west and south (Lorenz and Gavin, 1984; figure 4). In the region north of Dupuyer Creek the Two Medicine Formation is conformably overlain by the marine Bearpaw Shale and conformably underlain by the marine Virgelle Sandstone (Cobban, 1955). South of Dupuyer Creek the Two Medicine Formation is directly overlain by a brackish water facies that grades upward into the Horsethief Sandstone, and in the vicinity of Wolf Creek, the formation is overlain by the terrestrial Saint Mary River Formation (Lorenz and Gavin, 1984).

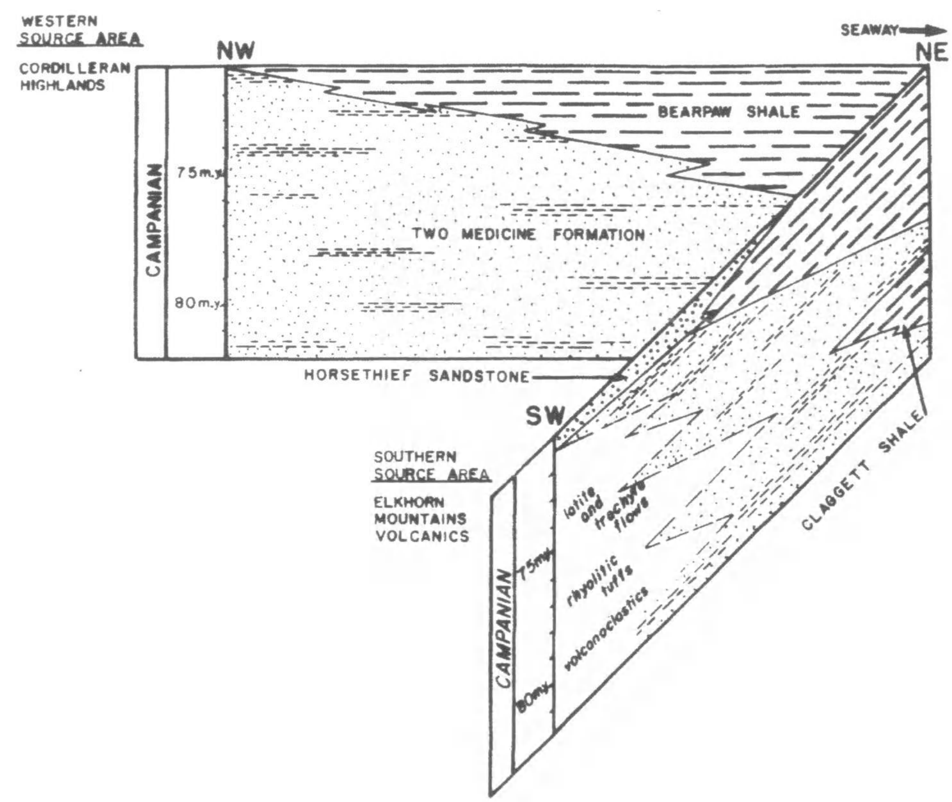


Figure 4--Fence diagram illustrating the upper diachronous boundary, regional stratigraphic relationships, and western and southern source areas of the Two Medicine Formation.

Rock types and facies relationships indicate that the Two Medicine Formation is almost entirely of fluvial origin. Fine-to medium-grained sandstone channel deposits are interstratified with more abundant, thicker sequences of silty and muddy interchannel deposits. Based on my observations, most of the vertebrate bone beds within the Two Medicine Formation occur in floodplain sediments.

Three lithofacies were identified by Lorenz (1981) at the type section of the formation. The lower lithofacies (lower 120 meters) consists of laterally extensive sandstone sheets interbedded with carbonaceous dark grey mudstones and non-carbonaceous grey-green mudstones. Sandstones remain interbedded with grey-green mudstones in the middle lithofacies (120 meters - 340 meters), but are no longer laterally continuous. In the upper lithofacies (340 meters - ±600 meters), greyish-purple, grey-green, and reddish-brown mudstone is common and large, laterally persistent sand bodies are rare. Differentiation between the middle and upper lithofacies is based upon the lowest occurrence of red or purple mudstone horizons (Lorenz, 1981; Lorenz and Gavin, 1984).

Lorenz (1981) interpreted the sandstone sheets of the lower lithofacies as deposits of distal, low-sinuosity delta plain rivers. He also concluded that the gradient on the delta plain was below the threshold of meandering. However, rare epsilon cross-beds in the lower lithofacies indicate lateral accretion. In the middle and upper lithofacies, discontinuous, thin sandstone lenses are enveloped in thick sequences of fine-grained floodplain mud and silt. Lorenz (1981) concluded that these sand bodies are deposits of shallow, braided, low-sinuosity streams located in mid to upper coastal plain settings. Mud drapes suggest that these streams were ephemeral, and the associated thick overbank deposits and the limited amount of channel incision signify that the system was aggrading (Lorenz, 1981). Paleocurrent data show that Two Medicine stream flow was predominantly to the northeast (Lorenz, 1981).

Approximately 90 meters of uppermost Two Medicine strata are exposed in the Landslide Butte field area. The Bearpaw Shale overlies the Two Medicine Formation in the field area, and is well exposed immediately to the south on Landslide Butte. Lorenz (1981) included the Landslide Butte strata within the middle lithofacies of the Two Medicine Formation. He based this decision on the absence of red or purple mudstone horizons, and the apparent similarity of the Landslide Butte strata with middle lithofacies strata. Lorenz attributed the absence of the upper lithofacies to increased distance from both the Cordilleran highlands and the Elkhorn Mountains volcanic pile, and to the presence at Landslide Butte of "a transitional environment ... contemporaneous with upland environments to the south" (Lorenz, 1981, p. 97).

I disagree with Lorenz's interpretation that middle lithofacies strata occur in the Landslide Butte field area, and I contend that typical deposits of the upper lithofacies of the formation are present at Landslide Butte. By definition, the upper lithofacies commences with the lowest occurrence of red or purple mudstone horizons (Lorenz, 1981, p. 98). Two red mudstone horizons occur in the Landslide Butte field area (figure 5). In addition, dinosaur eggshell is incredibly abundant in the Landslide Butte field area. Lorenz found that dinosaur eggshell occurred commonly in the upper lithofacies, but only rarely in the middle lithofacies. Finally, numerous well developed caliche horizons occur in the Landslide Butte field area. Pedogenic calcareous horizons were described by Lorenz in the upper lithofacies, whereas only "scattered" carbonate nodules were reported in the middle lithofacies.

Discontinuous, fine-grained ribbon sand bodies occur in the Landslide Butte field area. None of the sand bodies observed were laterally extensive, and most were on the order of one or two meters thick. Lower contacts are sharp and erosional, with minor local relief. Reworked clasts of the sediment directly underlying the sandstone lenses, caliche nodules, dinosaur bones, fossil wood, and unionid bivalves occur as basal lag deposits. All coarse lag material is solely of intrabasinal origin. Internal stratification consists of sets of trough cross-beds, ripple

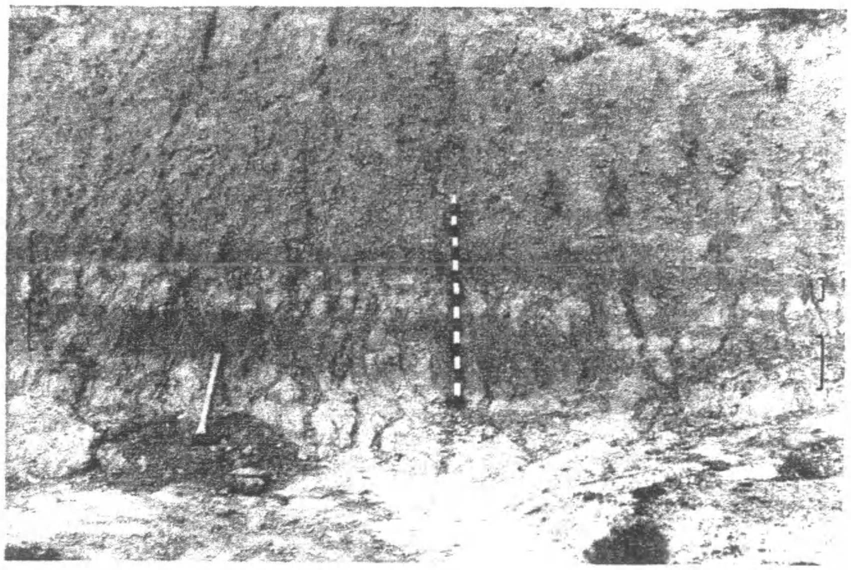


Figure 5--Two laterally persistent red horizons in the Landslide Butte field area. Red horizons are bracketed.

scale cross-lamination, and planar lamination. Cross-bed set size and grain size commonly decrease upward; trough cross-beds in sets up to 50 centimeters thick occur in the lower parts of channel deposits, smaller scale trough cross-bed sets, ripple cross-lamination, and planar lamination occur in the upper parts of the sand bodies (figure 6). Upper contacts of the Landslide Butte sandstone channels grade from fine-grained sandstone conformably upward into ripple cross-laminated siltstone and silty mudstone.

Root traces and burrows frequently occur at the upper contacts of the sand bodies (figure 7). I interpret the Landslide Butte sand bodies as channel fill and point bar deposits of aggrading, shallow, low-sinuosity streams.

More than 70% of the exposed strata in the Landslide Butte field area consists of mudstone and muddy siltstone. Most of these fine-grained deposits are massive, grey-green, and bentonitic, although two reddish-brown mudstone horizons extend across the field area. Pedogenic features such as root casts and root mottles, pedogenic slickensides, pedotubules, cutans, and nodular caliche horizons are common within mudstone horizons. The abundance of fossil soil features indicates that much of the floodplain was subaerially exposed and subjected to pedogenesis during the Campanian. Occasional dark grey organic rich siltstone horizons containing freshwater invertebrates and abundant carbonized plant debris directly overlie channel sandstones. These horizons were probably deposited in shallow, heavily vegetated oxbow lakes. A laterally extensive bentonite horizon provides stratigraphic control in the field area.

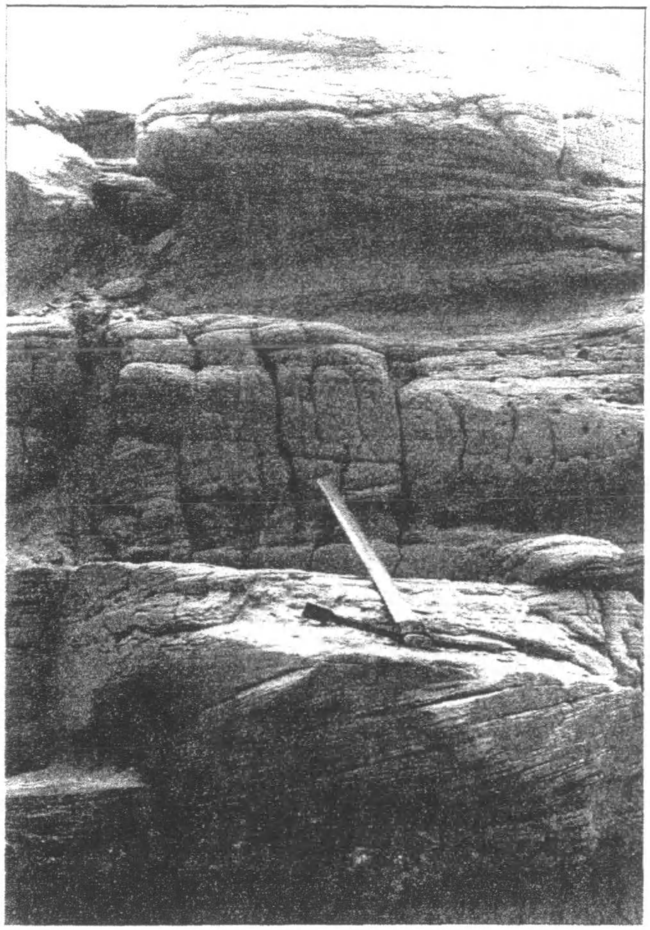


Figure 6--A typical Landslide Butte sandstone channel deposit consisting of a basal lag of caliche debris overlain by interstratified sets of trough cross-beds, ripple scale cross-lamination, and planar lamination. This particular paleo-channel crops out eight meters above Westside Quarry. The Marsh pick is 55 cm. long.

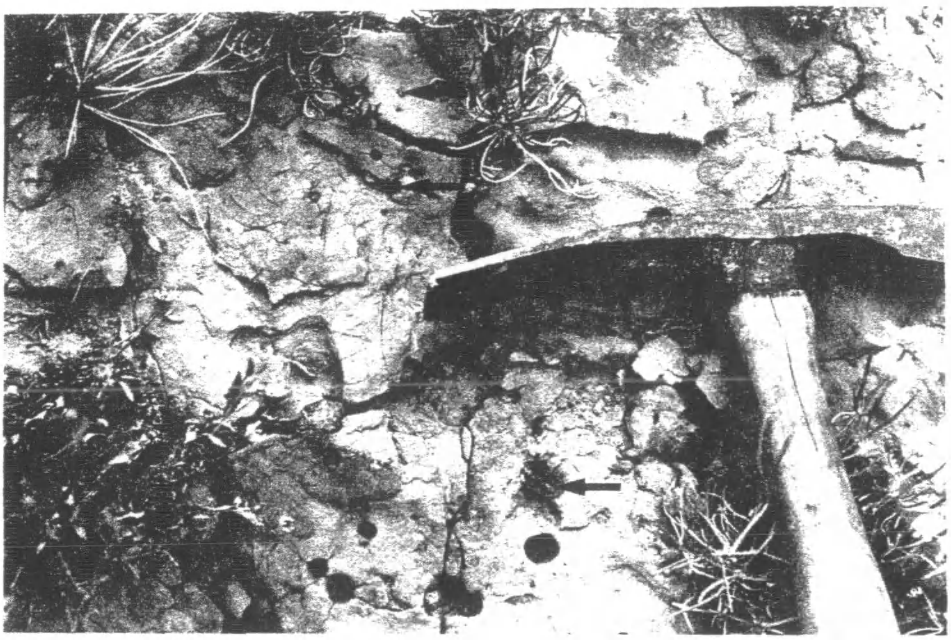


Figure 7--Root traces and invertebrate burrows are common on the upper surfaces of Landslide Butte channel deposits. Burrows average 1 cm. in diameter and are typically vertical and infilled by sand; root traces are usually smaller in diameter and oxidized. Arrows indicate root traces.

Most of the dinosaur remains in the Landslide Butte field area occur within interchannel mudstone and siltstone horizons. Westside Quarry occurs within a grey-green mudstone horizon; Canyon Bone Bed and Dino Ridge Quarry both occur within dark grey organic rich siltstone horizons. By definition (Carpenter, 1989), true bone beds occur exclusively within fine-grained floodplain sediments in the Landslide Butte field area.

Paleogeography of the Two Medicine coastal plain--

The Two Medicine Coastal plain was bounded to the west by the rising mountain ranges of the North American Cordillera and sloped eastward toward the Late Cretaceous Interior Seaway (figure 8). Both of these geographic features were formidable barriers controlling available habitats and the east-west movements of animals living upon the coastal plain (Horner, 1984). Apparently no major physical boundaries restricted north-south migration on this coastal plain, although the Elkhorn Mountains could have significantly affected animal migrations to and from the south during major eruptive episodes.

Gavin (1986) estimated a minimum elevation for the Cordilleran highlands of 1.8 kilometers above sea-level. He based this estimate on the thickness of the strata overlying the Proterozoic Bonner Formation, which was thrust upward and exposed to erosion during deposition of the Two Medicine Formation. Gavin also proposed a mean height of three to four kilometers above sea-level for the Cordillera based on comparison of the Cordilleran highlands with modern mountain systems in comparable tectonic settings.

The width of the Two Medicine coastal plain in northwestern Montana can be estimated by combining the strandline data of Gill and Cobban (1973) with palinspastic restorations of the position of the overthrust belt during the Late Cretaceous. The Lewis Thrust, the leading thrust of the Cordilleran Overthrust Belt in northwestern Montana, is presently 60 kilometers west of the Landslide Butte field area. During the Late Cretaceous, the eastern margin of the overthrust belt was at least 100 kilometers west of it's present position (Sears, pers. comm., 1988). Strand-line data of Gill and Cobban (1973) place the transgressive Bearpaw strand approximately 100 kilometers east of the Landslide Butte field area during genesis of the Landslide Butte bone beds. Therefore, the latest Campanian Two Medicine coastal plain in northwestern Montana was at least 260 kilometers wide. The Landslide Butte field area was situated near the center of this coastal plain, at a paleo-latitude of approximately 48 degrees north (Habicht, 1979).

The nearly horizontal attitude and continuity of the mudstone horizons and bentonite beds exposed both in the Landslide Butte field area and along the type section of the formation indicate that the Two Medicine coastal plain was nearly flat. Levees, if well developed, were probably the high spots, shallow lakes and stream channels occupied the low-lying areas. However, the coastal plain region proximal to the overthrust belt during the Campanian was probably elevated by small-scale faulting and folding, and thus had a more variable topographic relief.

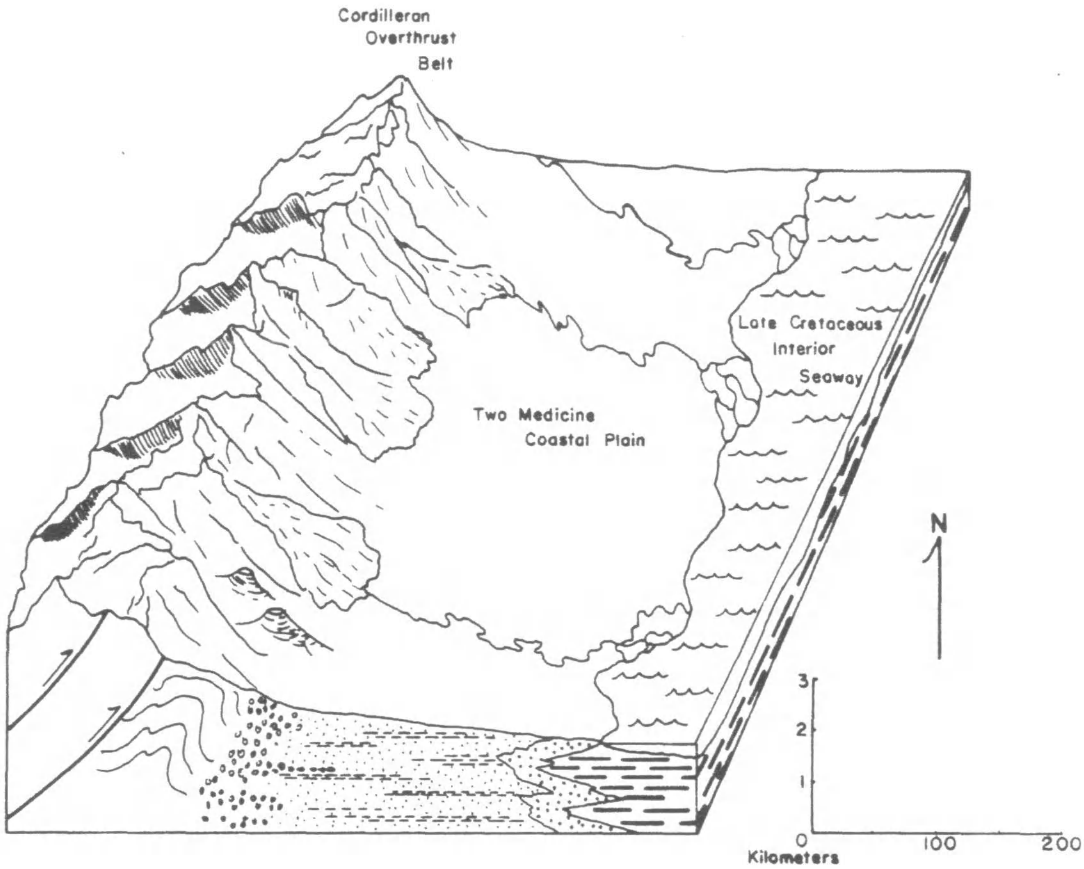


Figure 8--Paleogeographic reconstruction of the Two Medicine coastal plain during the Campanian Stage.

Paleoclimate--

Almost every event capable of generating and preserving a monospecific mass death vertebrate assemblage is either directly or indirectly influenced by climate. Diurnal and seasonal variations in temperature and humidity influence the weathering of subaerially exposed bone (Behrensmeyer, 1978), and fluvial processes and sedimentation rates are directly affected by climate (Langbein and Schumm, 1982). Once buried, bones are subject to a variety of climatically controlled pedogenic processes. Present day climatic effects can alter or destroy shallowly buried fossil deposits. A thorough understanding of the climate (modern and ancient) is obviously vital to any taphonomic study.

Lorenz (1981) and Gavin (1986) both concluded that the Two Medicine Formation was deposited under a seasonal, semiarid climatic regime with a long dry season, warm temperatures, and predominant winds from the west. Evidence cited in support of their conclusions includes caliche horizons, desiccated caliche nodules (septarian nodules), mud drapes in sand bodies, red oxidized paleosol horizons, abundant mud rip-ups in channel lags, unstable rock fragments and mineral grains in channel sands, an impoverished aquatic fauna, and a scarcity of lacustrine deposits. Gavin (1986) integrated models of atmospheric circulation with Campanian paleogeography and suggested that the Cordilleran highlands exerted a substantial rainshadow effect upon the Two Medicine coastal plain. He also proposed that rainfall occurred primarily during summer convective storms, and that the rest of the year was fairly dry.

Fossil plants collected from the lower lithofacies of the Two Medicine Formation by Crabtree (1987), specifically coriaceous fossil leaves without drip tips, large deciduous fossil leaves (mesophyll and megaphyll), and fossil wood with prominent growth rings of variable thickness, corroborate the foregoing seasonal, semiarid paleoclimatic interpretation. In addition, Jerzykiewicz and Sweet (1988) described an impoverished palynologic flora in the Belly River Formation of southwestern Alberta about 100 kilometers north of the Landslide Butte field area. Considering the proximity of their study area and their discovery of a southward trend toward aridity in the Campanian sediments in the foothills of the Canadian Rockies, it is likely that an impoverished palynological assemblage also characterizes the Two Medicine Formation.

Occasional drought conditions may have affected the Two Medicine ecosystem (Carpenter, 1987). Climatic criteria favorable for drought, namely seasonally variable precipitation, warm temperatures, and recurrent wind, characterize the Two Medicine paleoclimate. High temperatures and wind increase evapotranspiration (Tannehill, 1947), and thus no doubt combined to make minor deficiencies of rainfall on the Two Medicine coastal plain more severe. Furthermore, Gavin's (1986) contention that rainfall occurred primarily during the summer evokes a scenario in which high summer temperatures and resultant elevated evaporation rates would have greatly reduced the effective precipitation (effective precipitation = total precipitation/evaporation).

Sanford (1979, p. 34) defined drought as "a rainfall-induced shortage of some economic good brought about by inadequate or badly timed rainfall". The severity and frequency of drought is therefore controlled not only by rainfall but also by the demand or need for the drought limited "economic good". When considering natural ecosystems, the "economic good" in short supply due to deficient rainfall is consumable vegetation. Demand for vegetation would increase as consumers immigrate into remaining productive regions during the dry season (Andere, 1981; Henshaw, 1972; Corfield, 1973; Hillman and Hillman, 1977), or if an encroaching geographic barrier, such as a transgressive seaway strand, diminished available habitat. Environmental stress would be especially severe if drought coincided with aerial habitat reduction.

The effects of drought on flora and fauna in modern ecosystems is well documented. Plant growth during drought is generally inhibited (Vaadia and Waisel, 1967; Treshow, 1970), and the digestibility and nutrient content of plants is lower during drought (Skarpe and Bergstrom, 1986).

Animal response to drought is highly variable and dependent upon the adaptability and water needs of the animal. Water-dependent species may migrate and congregate in regions with persistent water sources during drought (Hillman and Hillman, 1977; Behrensmeyer, 1981; Gifford, 1985; Western, 1975; Henshaw, 1972). Over population may lead to decimation of remaining food resources around water sources (Ayeni, 1975; Shipman, 1975; Corfield, 1973). Mortality of animal life during drought is usually ascribed to starvation (Corfield, 1973) and malnutrition, parasite infestation, and disease (Hillman and Hillman, 1977; Gifford, 1985; Carpenter, 1987). Carpenter (1987) suggested that sunstroke may have caused mortality among dinosaurs during drought.

Unfortunately, few, if any, definitive criteria exist for the recognition of drought in the geologic record. Carpenter (1987) suggested that fusinite (fossil charcoal) is a reliable indicator of drought since range and forest fires are common consequences of drought. Regrettably, the preservation potential of fusinite is limited in oxidizing sedimentary environments, and its presence cannot exclusively be attributed to drought (Sander, 1987). Shipman (1975) suggested that vertebrate death assemblages generated by drought may have an unusually high probability of being represented in the fossil record. She proposed several geologic and paleontologic criteria for recognizing a severe drought in the rock record. These include: (1) desiccation cracks, caliche and evaporites associated with the fossil deposit, (2) rapidly deposited entombing sediments, (3) fossils located near fluvial, lacustrine, or tiphic sediments, (4) age distribution of individuals within fossil assemblage indicative of catastrophic mortality and (5) minimal scavenger disturbance of the fossil deposit. Shipman stressed that none of these criteria alone should be used to infer drought, and that every drought assemblage will not exhibit all of these criteria.

PART THREE--TAPHONOMIC DATA

Taphonomic data are presented separately for Canyon Bone Bed, Dino Ridge Quarry, and Westside Quarry. Data are organized under two subheadings: geologic data and biologic data (after Voorhies, 1969). Geologic data include bone bed stratigraphy and sedimentology, bone orientation and transport, and physical and chemical bone modification. Depositional environments are interpreted from these geologic criteria. Biologic constraints and modifications are presented under biologic data. Biologic constraints include the taxonomic composition, numeric content, and age distribution of individuals within the bone beds. Modifications produced by biologic agents include scattering and breakage caused by trampling, and the effects of scavengers.

The mode of fossilization is analogous in all three quarries. Fossil bone is permineralized by calcium carbonate, and the original bone structure is beautifully maintained. Figure 9, a photomicrograph of a transverse section through a rib from Canyon Bone Bed, illustrates the type of preservation common to all three quarries. The locations of the bone beds and other pertinent fossil localities in the Landslide Butte field area are illustrated in figure 10. Diagrammatic stratigraphic sections (figure 11) demonstrate relative temporal positions of the bone beds and their facies relationships. Reference to these sections will be made as data for each bone bed are presented. Detailed measured sections are presented in appendix #1. Bone bed maps and a list of skeletal elements within each quarry are presented in appendix #2.

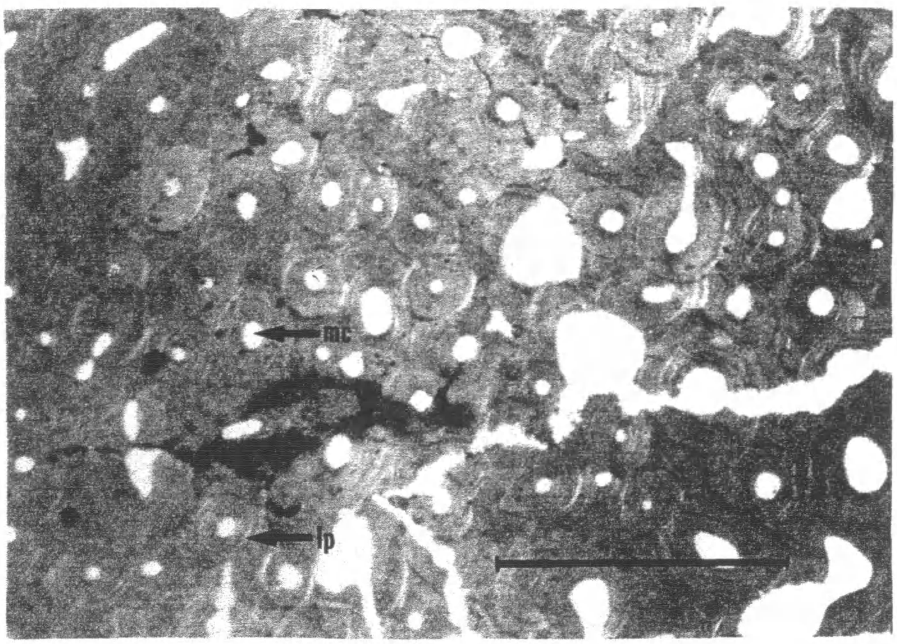


Figure 9--Photomicrograph of a transverse section through a rib from Canyon Bone Bed. The main canals (mc) and lamellar plates (lp) of the Haversian system are clearly visible. Calcium carbonate has infilled the interstices of the main canals. This type of preservation is common to all three quarries. Scale bar is 1 mm.

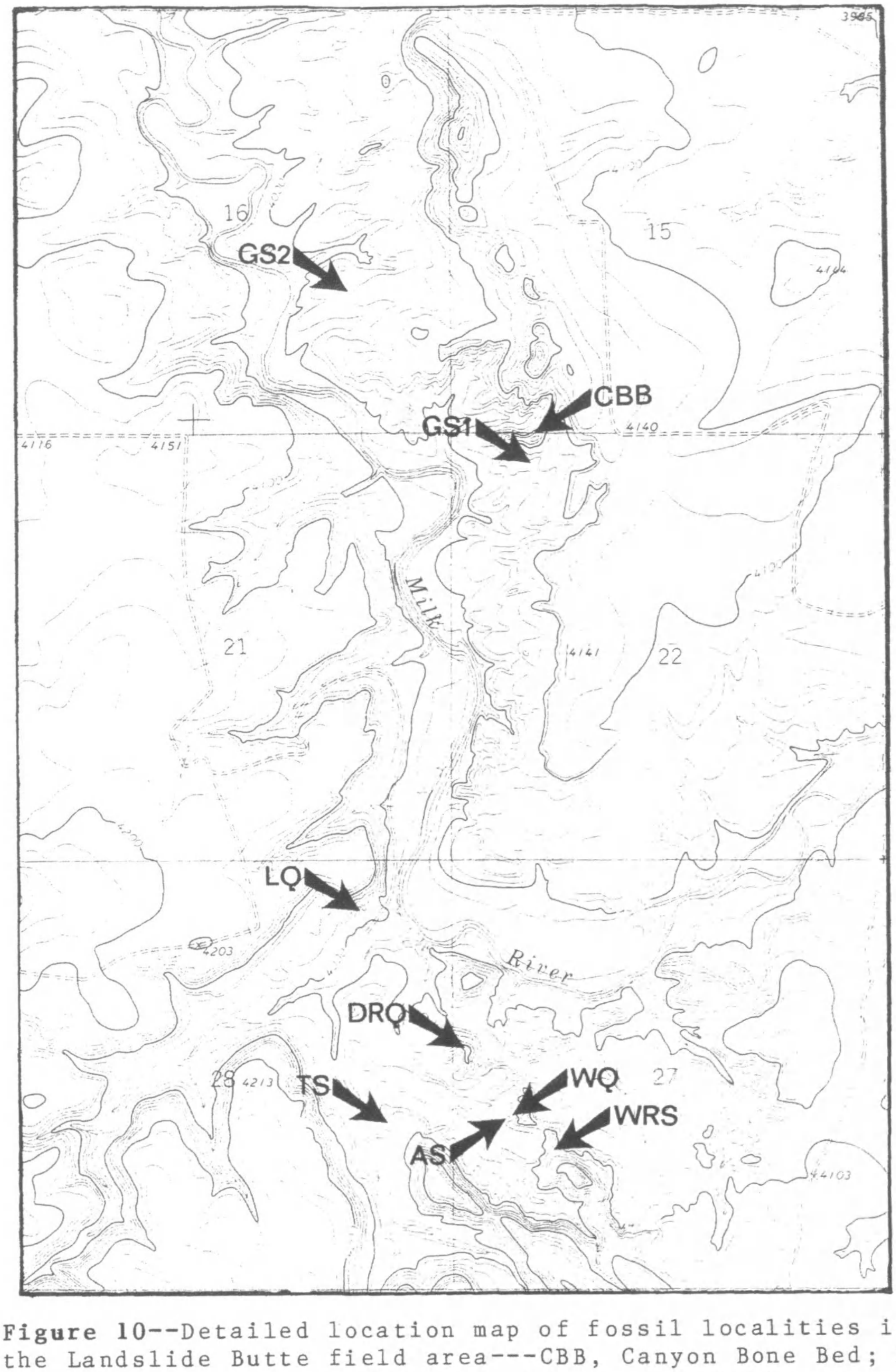


Figure 10--Detailed location map of fossil localities in the Landslide Butte field area---CBB, Canyon Bone Bed; DRQ, Dino Ridge Quarry; WQ, Westside Quarry; LS, Lambeosite; WRS, Windy Ridge Site; AS, Ank Site; TS, Trailside Site; GS1, Gilmore Site 1; GS2, Gilmore Site 2.

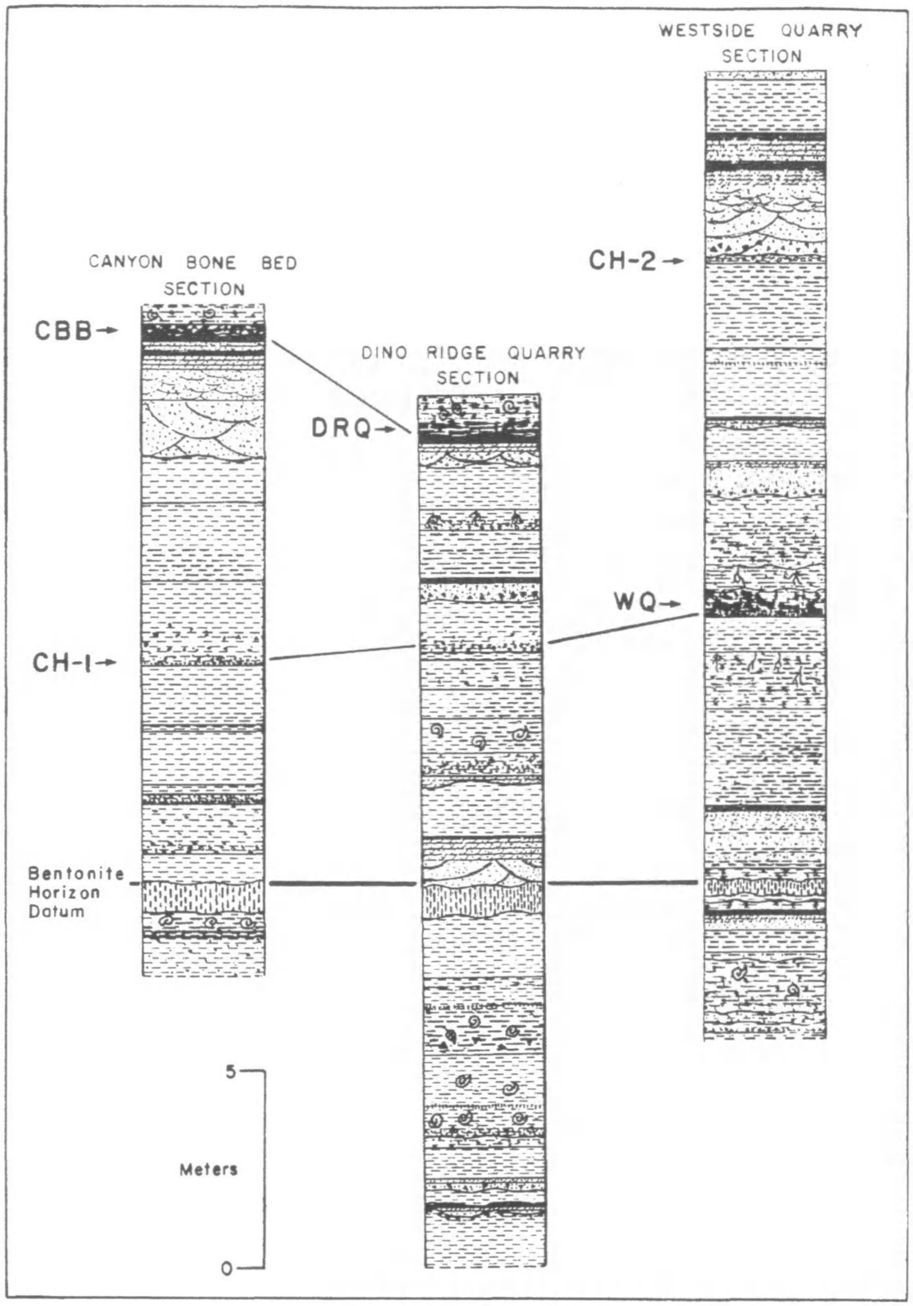


Figure 11--Diagrammatic stratigraphic sections measured through Canyon Bone Bed, Dino Ridge Quarry, and Westside Quarry. The explanation for the three sections is on the following page. Detailed descriptions of these measured sections are presented in appendix #1.

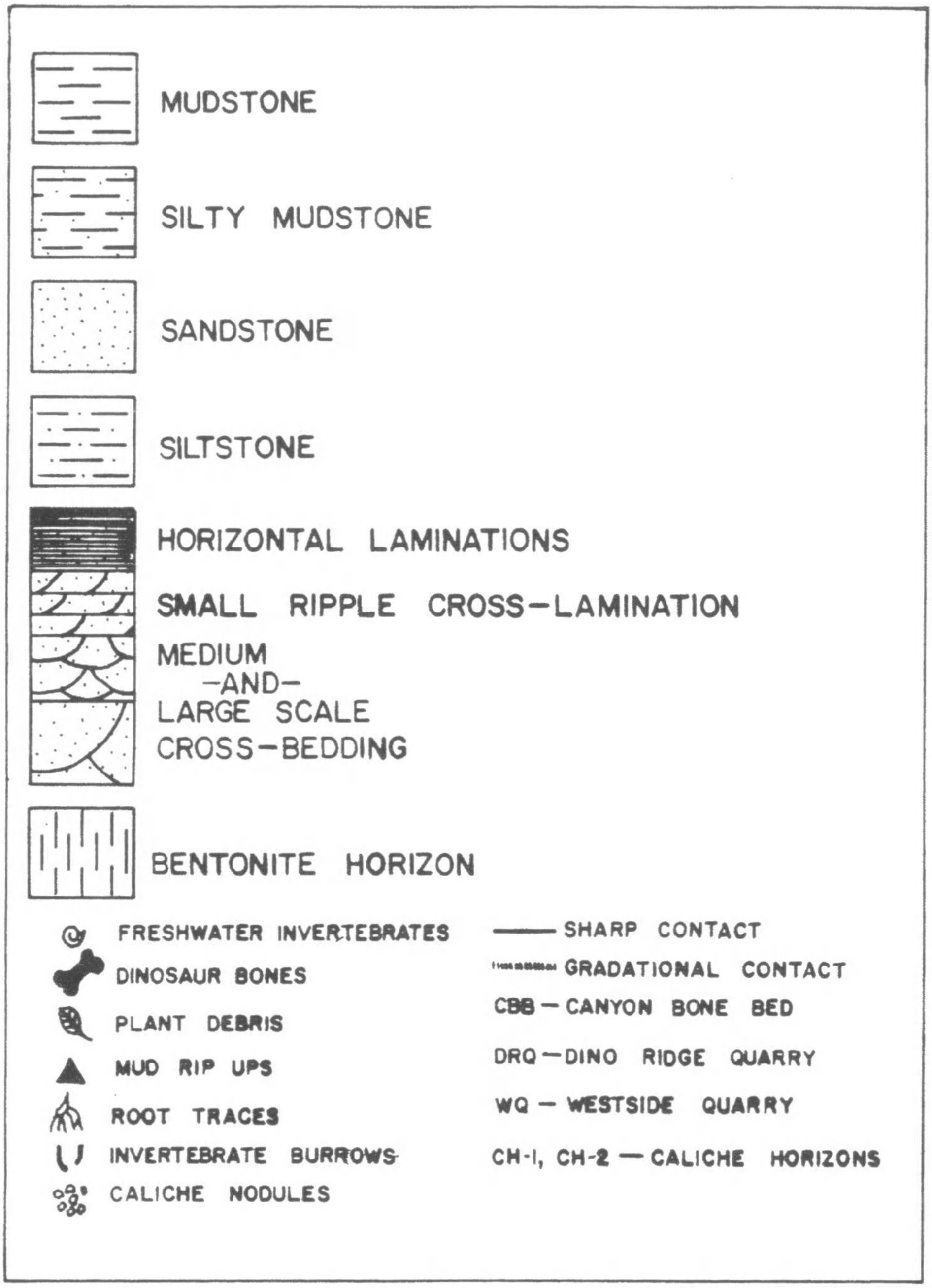


Figure 11--continued...explanation for stratigraphic sections.

CANYON BONE BED

Geologic data--

Stratigraphy, sedimentology, and depositional environment--Canyon Bone Bed occurs 14.6 meters above the bentonite datum in the Landslide Butte field area (figure 11). The bone bed lies sharply above cross-bedded fluvial sandstone and abruptly below lacustrine siltstone. To the east and west, the bone bed is cut by channel sandstone. Recent erosion has removed bone-bearing sediments to the north, but the bone bed horizon continues southward into the hillside (figure 12). The aerial extent of quarry excavation is approximately 23 m^2. The thickness of the bone bed horizon varies, but averages 20 cm. A well developed caliche horizon (CH-2) is stratigraphically equivalent to Canyon Bone Bed (figure 11, Westside Quarry Section).

The sedimentary matrix of Canyon Bone Bed consists of dark brown (Munsell notation: 2.5 Y 4/2), massive to blocky, poorly indurated, organic-rich sandy siltstone. Clastic grains are poorly sorted and angular, grain size ranges from silt to fine sand. Major detrital constituents include quartz, plagioclase and potassium feldspar, and chert. Minor detrital constituents consist of volcanic, metamorphic, and sedimentary rock fragments, pedoclasts (eroded from nearby epipedons), biotite, muscovite, microcline, and amber. Some quartz and feldspar grains are partially to fully replaced by authigenic calcite. Small transported calcium carbonate nodules and mud clasts are scattered throughout the bone bed horizon.

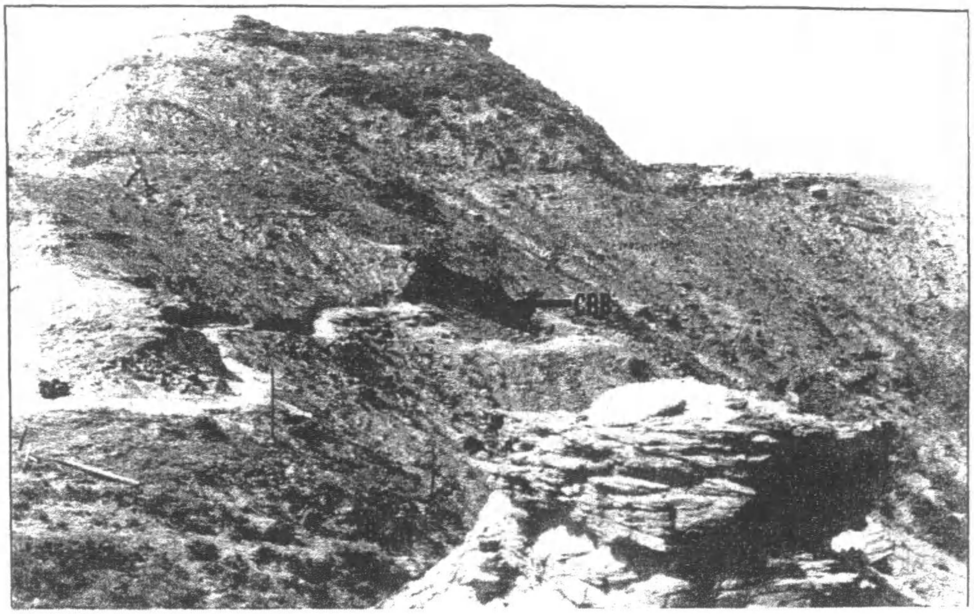


Figure 12--View of Canyon Bone Bed from the east. The bone-bearing horizon continues for an indeterminate distance southward into the hillside.

Matrix and cement comprise approximately 20 percent of the rock, and consist of clay minerals intermixed with amorphous organic debris and microcrystalline calcium carbonate. X-ray diffraction analysis shows that the predominant clay mineral is smectite, with only minor to trace amounts of mixed layer illite/smectite, illite, and kaolinite. Horizontally laminated carbonaceous plant debris and fragmentary remains of small freshwater gastropods and bivalves are common. Primary sedimentary structures were not observed in quarry sediments.

The presence of freshwater invertebrates and the organic-rich nature of the sediments indicate that Canyon Bone Bed was deposited in a shallow lake or pond. Bone bed sediments directly overlie fluvial channel deposits, suggesting that the lake occupied an abandoned stream channel or channel cut-off, and thus was an oxbow lake. The abundance of carbonized plant debris suggests that the lake was lushly vegetated, and that the lake sediments were probably reducing (Stashchuk, 1972; Tucker, 1981).

Physical and chemical modifications--More than 150 disarticulated skeletal elements were collected from Canyon Bone Bed. Most of the fossil bones in the sample are in very good condition and are identifiable, some bones have been slightly crushed by lithostatic compaction. The various skeletal elements in the Canyon Bone Bed sample are not representative of complete animals. Normally abundant bones, such as vertebrae, ribs, and phalanges, are uncommon. In fact, only 10 vertebrae, 10 phalanges, and fewer than 20 complete ribs have been collected from the quarry. In contrast, disarticulated cranial elements and most limb bones are relatively abundant, representing more than 80 percent of the sample (table 1, appendix #2).

I believe the scarcity of certain skeletal elements within Canyon Bone Bed is primarily a result of episodic exposure of the *Styracosaurus* death assemblage to stream current. The abandoned channel may have been reoccupied during seasonal floods and flow may have resumed within the oxbow lake. Preferential transport of easily mobilized skeletal elements during flooding would account for the differential retention of certain bones in the bone bed as proposed by Voorhies (1969). Voorhies investigated the current sorting of mammal bones in stream table experiments and recognized discrete bone transport groups. He found that: 1) the skull and jaws are most resistent to transport by currents and thus commonly form lag deposits, 2) most limb bones are also resistent to current transport, but to a lesser degree than the skull and jaw, and 3) vertebrae, ribs, phalanges, sacra, carpals, radii, and ulnae are easily transported by currents. Lawton (1977) addressed the problems of applying transport groups based on mammal bone hydrodynamics to dinosaur assemblages. More recently, Lehman (1982) proposed bone transport groups based on the analysis of a winnowed ceratopsian bone bed. He concluded that ceratopsian bones do indeed respond similarly to large mammal bones when exposed to current.

Canyon Bone Bed was probably winnowed before extensive bioturbation since small, dense skeletal elements (caudal vertebrae, phalanges, podials, etc.) are rapidly interred into soft sediments by trampling (Behrensmeyer, 1984; Behrensmeyer, Western, and Dechant Boaz, 1979; Gifford, 1985). However, if the flood events were particularly intense or persistent, winnowing currents may have repeatedly scoured the lake bottom and exhumed bones, exposing them again and again to current sorting. The fossil bones preserved in Canyon Bone Bed do not show any evidence of current abrasion. The spatial arrangement of bones in the quarry is primarily a result of bioturbation, and will be addressed under biologic modifications.

An unusual feature of many bones in Canyon Bone Bed is the difference between opposite bone surfaces (figure 13). This characteristic is most commonly found on flat or nearly flat cranial elements. Typically, one bone surface is rough, with the outermost surface of the bone removed. The opposite surface is largely unaltered and smooth, with no indication of pre-burial cracking or exfoliation. Bones in the sample that are not differentially weathered have surfaces similar to the unaltered surface of differentially weathered bone. A possible explanation for this phenomena is that the chemistry of the water in the lake fluctuated between the rainy and dry season (Carpenter, 1987b). The upward-facing surface of those bones resting on the lake bottom may have been chemically attacked, with the end result deterioration of the exposed bone surface. The sediment - bone interface would have been more stable, resulting in better preservation of the downward-facing side.

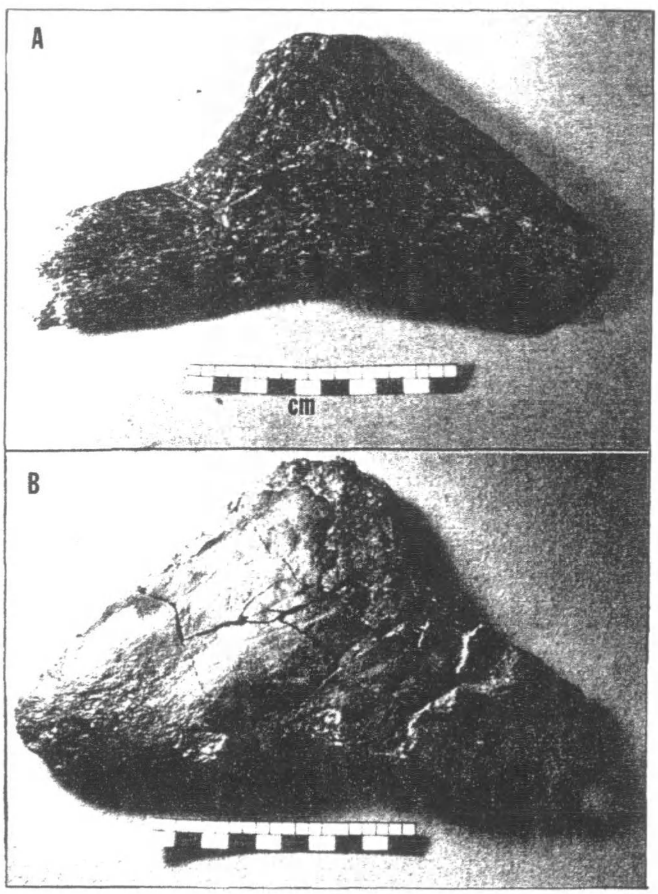


Figure 13--A differentially weathered cranial fragment from Canyon Bone Bed. Most fossil bones in the sample display this type of weathering. (A - upward-facing side; B - downward-facing side.

Biologic data--

Biologic constraints--Systematic description of the animals preserved in Canyon Bone Bed and their counterparts in Dino Ridge Quarry is in progress (Sampson, pers. comm., 1989). Preliminary investigation indicates that Canyon Bone Bed contains at least seven undescribed individuals of the genus *Styracosaurus*. This estimate is based on the number of mutually exclusive skeletal elements in the bone sample, and also reflects consideration of size variations within the sample. Tentative evaluation of bone bed age structure suggests that six adult animals and one juvenile are represented. This estimate was established solely on size variation. A more accurate evaluation of bone bed composition and age structure will be possible when systematic description of the animals is complete.

Biologic modifications--All fossil remains preserved within Canyon Bone Bed are disarticulated except for two partial skulls (see plate 1, appendix #2). Association of skeletal elements is poor. Almost all of the fossil bones mapped in the quarry are flat lying. Interference between bones and irregularities on the underlying sandstone surface account for those bones that deviate far from horizontal. The azimuth of the bones shows no preferred orientation, hence bones are randomly scattered in a horizontal plain. Figure 14, a lower hemisphere stereographic projection, illustrates the orientation of bones in the quarry.

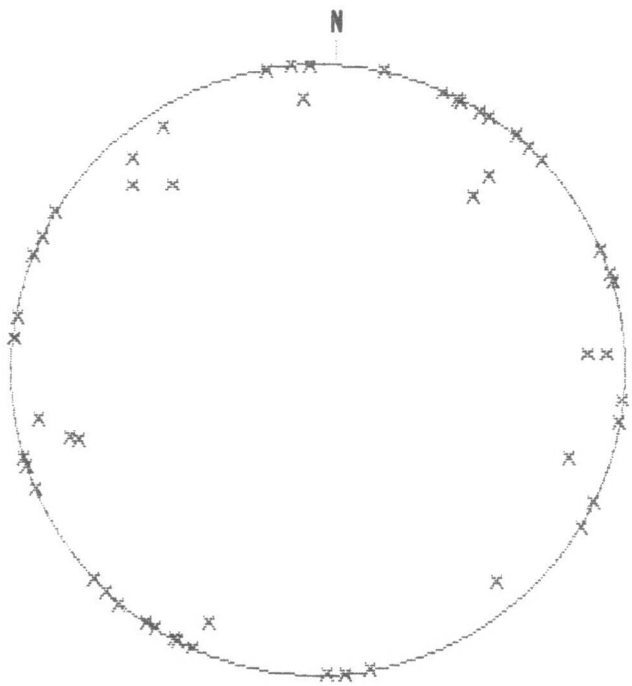


Figure 14--Lower-hemisphere stereographic projection (Schmidt net) of bone trend and plunge data for elongate skeletal elements in Canyon Bone Bed. Fossil bones are randomly oriented in a horizontal plain. Horizontal bones are plotted in both the northern and southern hemispheres. Total sample n = 34.

Numerous bones preserved within Canyon Bone Bed are fragmentary. Bone fragments disseminated within the bone bed matrix and dissociated broken bones indicate that they were broken either prior to burial or within unconsolidated surficial sediments. Minute scratch marks cover most bone surfaces (figure 15), and tooth marks occur on two bones in the sample (figure 16).

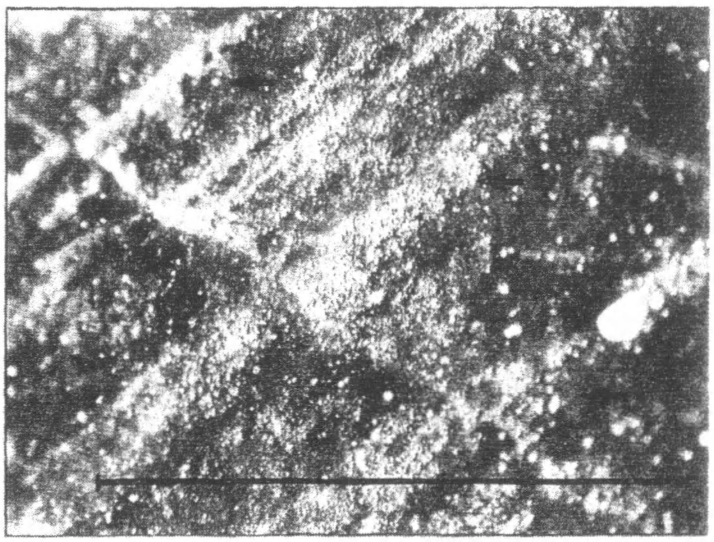


Figure 15--Minute scratch marks on the surface of a cranial fragment collected from Canyon Bone Bed. Similar scratch marks occur on nearly all bones in the sample. These scratch marks are presumably the result of trampling of the bones through abrasive quarry sediment. Scale bar is 1 mm.

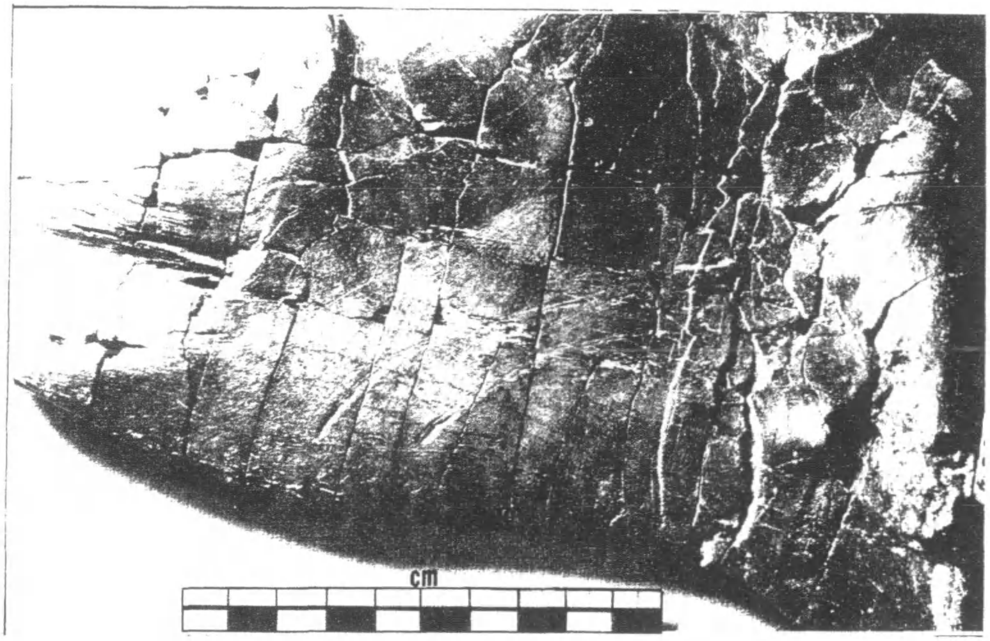


Figure 16--Tooth marks on a left jugal collected from Canyon Bone Bed. The tooth marks are most likely the result of scavenging since there is no indication of osteopathic healing.

Disarticulation, breakage, and surficial scratching of bones can be explained by bioturbation and trampling of Canyon Bone Bed by scavengers and herbivores frequenting the site of mortality. Studies of recent bone assemblages clearly indicate that scavenging and trampling are principal causes of disarticulation, scattering, fragmentation, and burial of bone on land and in low-energy, shallow subaqueous settings (Hill, 1979; Conybeare and Haynes, 1984;

Gifford and Behrensmeyer, 1977; Behrensmeyer, 1981; Gifford, 1985). The surface scratch marks can also be explained by trampling of the bone deposit (Behrensmeyer, Gordon, and Yanagi, 1986). The pervasiveness of the surface scratches suggests that at least some of the bones were trampled after burial within abrasive quarry sediment. The lack of bones oriented in unstable positions could be explained by a fluid, unconsolidated encasing matrix that allowed any bones jostled into unstable positions by trampling to return to stable, low-energy orientations. It is also possible that scouring of the lake bottom undermined bones in unstable orientations, causing their collapse to a more stable position. The tooth marks are almost certainly a result of scavenging of the styracosaur death assemblage since there is no indication of osteopathic healing. Scavengers probably also heightened the extent of differential preservation in the bone bed by preferentially carrying-off or consuming smaller skeletal elements (Behrensmeyer, 1981). Numerous theropod teeth were recovered from the quarry.

DINO RIDGE QUARRY

Geologic data--

Stratigraphy, sedimentology, and depositional environment--Dino Ridge Quarry is 12 meters above the bentonite datum, and is stratigraphically correlative to Canyon Bone Bed (figure 11). The 2.6 meter difference in stratigraphic position between bone beds is probably attributable to topographic relief on the Two Medicine coastal plain. Dino Ridge Quarry crops out at the top of a badland butte (figure 17), and rests directly upon fine-grained, cross-bedded sandstone deposited in a fluvial channel. The bone bed horizon is traceable to the butte immediately southeast of the quarry. All of the outcrop on top of the butte has been explored, and a total of 76 m^2 have been excavated. The quarry horizon is about one meter thick; most bones were concentrated in the lower 35 centimeters.

The sedimentology and paleontology of Dino Ridge Quarry are identical to that of Canyon Bone Bed. Therefore, the depositional environment of Dino Ridge Quarry was probably an oxbow lake similar to that of Canyon Bone Bed, although stratigraphic relationships suggest that the lake containing Dino Ridge Quarry may have been slightly deeper. Dino Ridge Quarry and Canyon Bone Bed preserve coeval death assemblages of *Styracosaurus* sp?.

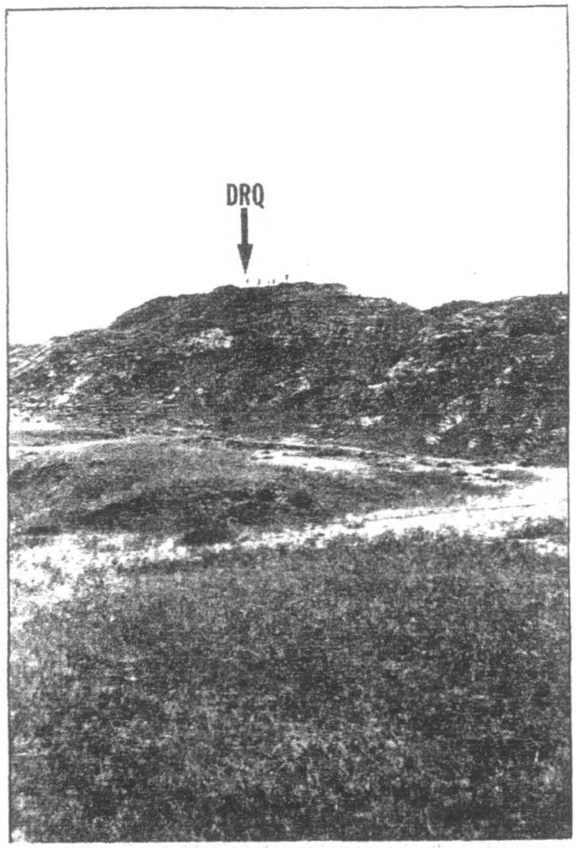


Figure 17--View of Dino Ridge Quarry from the north.

<u>Physical and chemical modifications</u>--More than 450 disarticulated skeletal elements were mapped in Dino Ridge Quarry (plate 2, appendix #2). Unfortunately, not all of the bones collected have been prepared, and thus some of the sample remains unaccessible and unstudied. The bone sample that has been prepared is virtually indistinguishable from the Canyon Bone Bed sample.

Bones that are easily transported by current are uncommon in Dino Ridge Quarry, cranial elements are abundant (table 1, appendix #2). I believe that the same fluvial processes were responsible for the differential preservation of bones in both Styracosaurus quarries. Most bones in Dino Ridge Quarry do not show the effects of current abrasion. However, a few water-worn bone fragments occur in the bone bed (figure 18); these bones were probably transported into the quarry from a stream channel during flooding and thus exemplify "background" bones of Lehman (1982). As in Canyon Bone Bed, bioturbation is responsible for the spatial arrangement of bones in Dino Ridge Quarry.

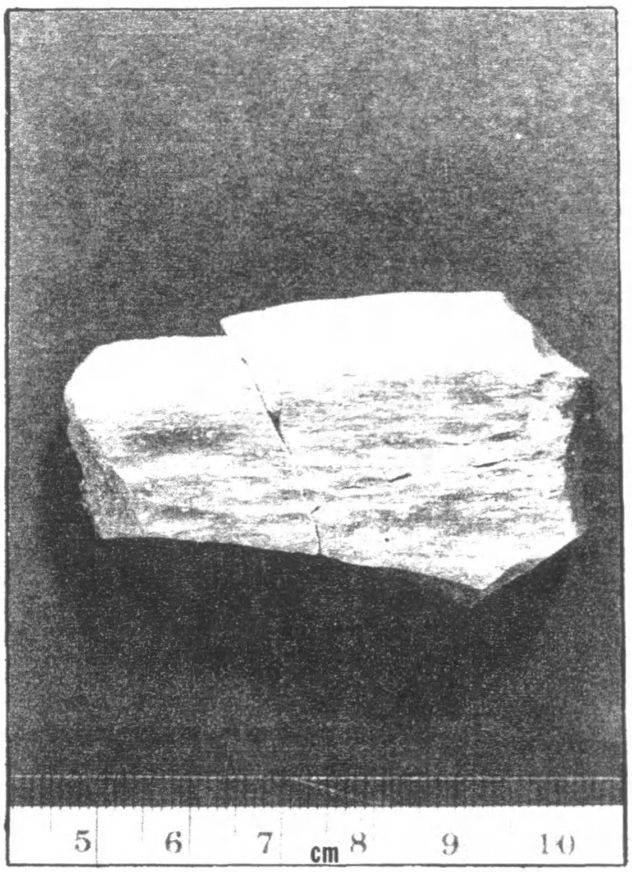


Figure 18--Water-abraded bone fragment collected from Dino Ridge Quarry. This fragment was probably washed into the quarry during flooding and is thus allochthonous.

Skeletal elements within Dino Ridge Quarry are not differentially weathered, and all bones display similar weathering characteristics. Bone surfaces are smooth, with no indication of surface cracking or flaking prior to fossilization. However, present day soil processes have adversely affected the original state of bone preservation and doubtlessly obscured some original surface features. Many bones in the quarry have deteriorated as a result of present day oxidation and desiccation (figure 19).

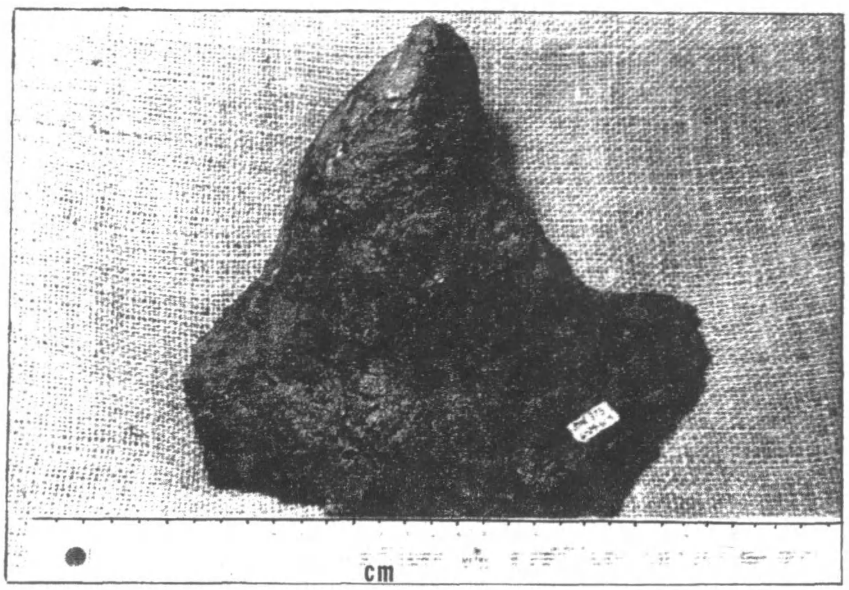


Figure 19--Highly weathered, oxidized right postorbital collected from Dino Ridge Quarry. This advanced weathering stage is a result of modern soil processes. Those bones in the upper levels of the bone bed horizon are most highly weathered.

Biologic data

Biologic constraints--The animals within Dino Ridge Quarry have not yet been systematically described. My observations indicate that Dino Ridge Quarry contains at least eight undescribed individuals of the genus *Styracosaurus* and two undescribed hadrosaurs. Three distinct size classes of *Styracosaurus* are preserved within the quarry. Assuming that these size variations reflect growth stages rather than sexual dimorphism, two adults, five subadults, and one juvenile are represented in the sample. The size of the hadrosaur remains indicate that both a juvenile and adult are represented (Sampson, pers. comm., 1989). In addition to dinosaur remains, small fragments of turtle carapace and a few teeth and vertebrae of *Champsosaurus* were recovered from the quarry.

Biologic modifications--All fossil remains within Dino Ridge Quarry are disarticulated and poorly associated (see plate 2, appendix #2). Bones in the quarry are nearly flat lying and have a random azimuth (figure 20). Many bones are broken, and some bones have minute surface scratch marks identical to those in Canyon Bone Bed. Tooth marks were not discovered on any bones in the Dino Ridge sample. However, a wide variety of theropod teeth were collected from the quarry (figure 21).

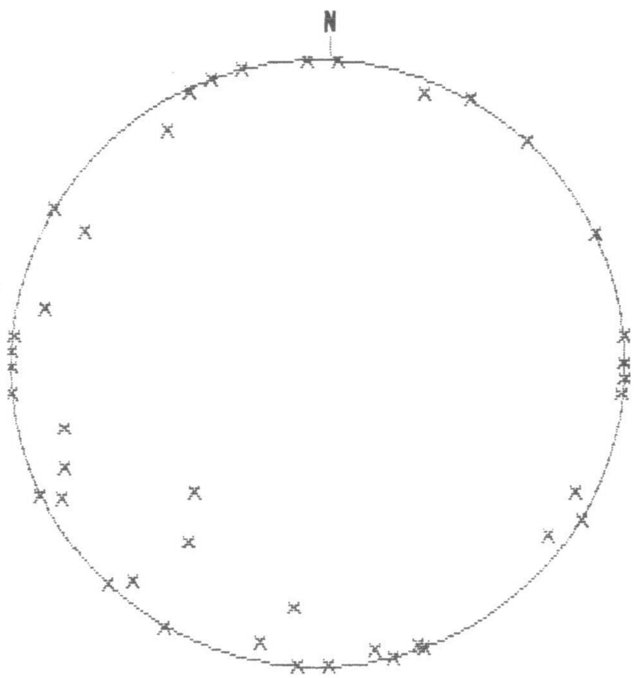


Figure 20--Lower-hemisphere stereographic projection (Schmidt net) of bone trend and plunge data for elongate skeletal elements in Dino Ridge Quarry. Fossil bones are randomly oriented in a horizontal plain. Horizontal bones are plotted in both the northern and southern hemispheres. Total sample n = 29.

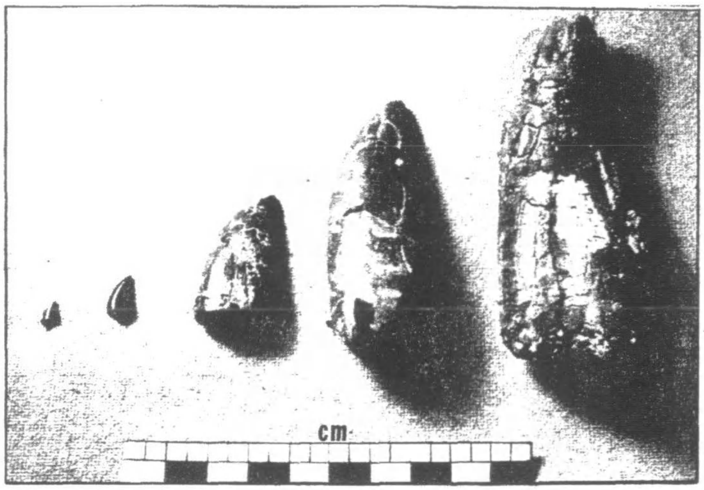


Figure 21--Various theropod teeth collected from Dino Ridge Quarry. Teeth range in size from < 5 mm. to > 10 cm.

Undoubtedly, the same biological processes that altered the bone sample of Canyon Bone Bed affected Dino Ridge Quarry. Bones were disarticulated, broken, and eventually interred by scavengers and herbivores feeding in and around, and passing through the bone bed. What may very well be the path of an animal that passed through the quarry is indicated on the bone bed map (see plate 2, appendix #2). This possible pathway is about 50 centimeters wide, and extends for nearly five meters through the center of the bone bed.

WESTSIDE QUARRY

Geologic data--

Stratigraphy, sedimentology, and depositional environment--Westside Quarry is seven meters above the Landslide Butte bentonite datum, and thus may have formed thousands of years prior to Canyon Bone Bed and Dino Ridge Quarry (figure 11). The bone bed rests directly upon a 20 - 25 centimeter thick caliche horizon (CH-1) that extends across the field area, and grades upward into a non-fossiliferous dark grey-green mudstone unit that contains scattered caliche nodules and root traces. The bone-bearing horizon is lensoidal and reaches a maximum thickness of 50 centimeters. The aerial extent of quarry excavation is approximately 47 m^2. Lenses of bone-bearing sediment crop out along strike to the north and south of the main quarry (ie. Southside Quarry). For the purposes of this investigation, the bone bed designated "Westside Quarry" will include all bones discovered within Westside Quarry and its nearby stratigraphic equivalent Southside Quarry (figure 22).

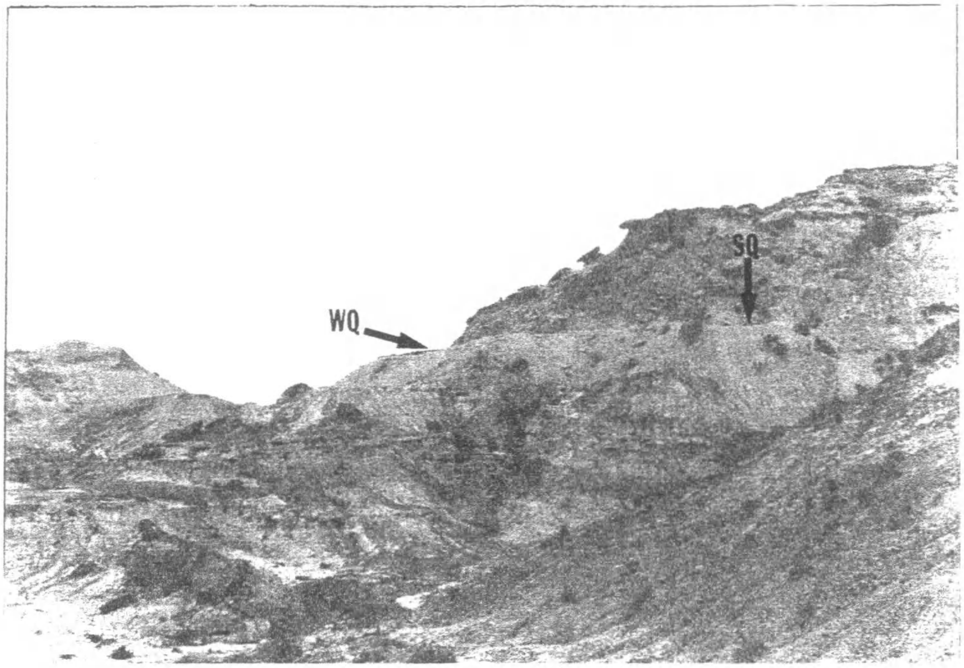


Figure 22--View of Westside Quarry (WQ) from the south. Southside Quarry (SQ) is stratigraphically equivalent to Westside Quarry and is presented with Westside Quarry in this report.

The sedimentary matrix of Westside Quarry consists of grey-green (Munsell notation: 5 GY 5/1), massive to blocky, poorly indurated silty mudstone. Silt grains are moderately sorted and angular, and consist primarily of quartz and plagioclase feldspar. Many of the silt grains are partially to completely replaced by authigenic calcite. More than 60 percent of the rock is comprised of clay; X-ray diffraction analysis indicates that the most abundant clay mineral is smectite, with only minor to trace amounts of mixed layer illite/smectite, illite, and kaolinite.

Primary sedimentary structures were not present in the quarry sediments. However, fossil soil features are preserved within Westside Quarry. These features include small vertical root traces, pedotubules, scattered caliche nodules, and pedogenic slickensides. A well developed caliche horizon occurs directly beneath the bone bed (figure 11). Micromorphologic paleosol features include thin, discontinuous cutans on some silt grains and lattisepic plasmic fabric (figure 23; Retallack, 1985). Incipient caliche nodules are also present within the bone bed matrix (figure 24).

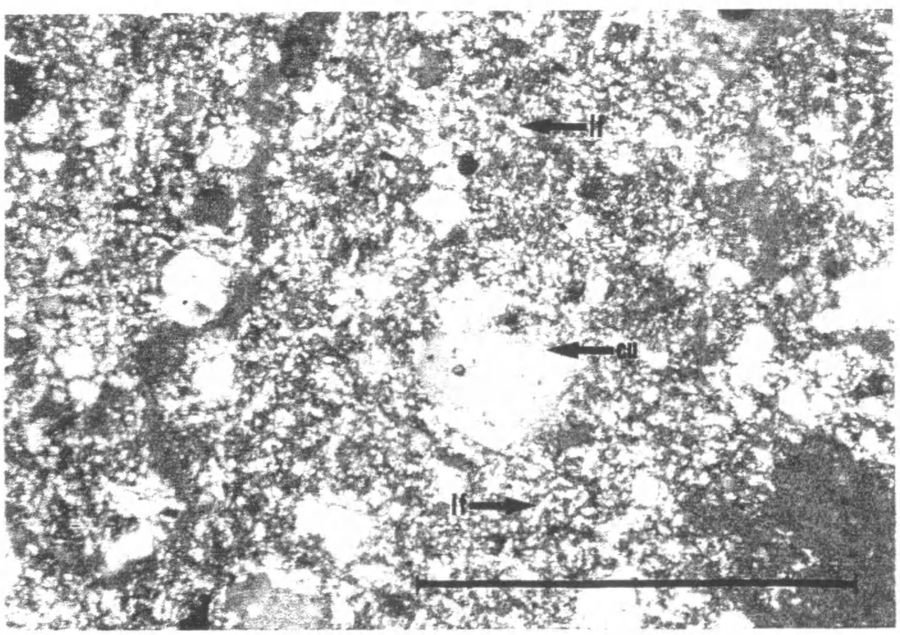


Figure 23--Thin, discontinuous argillic cutans (cu) and lattisepic plasmic fabric (lf -- perpendicularly oriented clay minerals) in the Westside Quarry matrix. Scale bar is .5 mm.

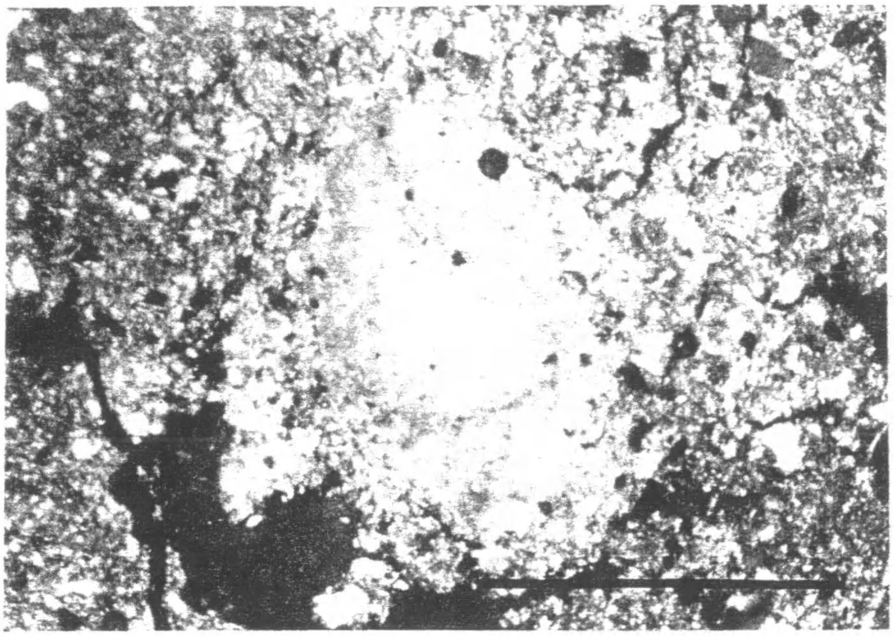


Figure 24--Incipient caliche nodule within the matrix of Westside Quarry. Scale bar is 1 mm.

Westside Quarry was deposited in what was originally a shallow depression floored by caliche on a floodplain of the Two Medicine coastal plain. Since pedogenic caliche horizons impede the downward movement of water, it is possible that this depression was an ephemeral water hole. The depositional event that interred the Westside Quarry bones was most likely an overbank flood. Bones within and around the perimeter of the water hole were buried in fine-grained overbank sediments deposited by the flood waters. Sediments deposited during flooding did not completely fill the depression, thus the site may still have occasionally become saturated and ponded water.

Physical and chemical modifications--More than 350 skeletal elements were found in Westside Quarry. Most of the bones within the quarry were disarticulated, although several articulated strings of caudal vertebrae were collected (figure 25). The state of preservation of fossil bone within the quarry is excellent, only a few bones are broken or crushed by diagenetic compaction (figure 26).

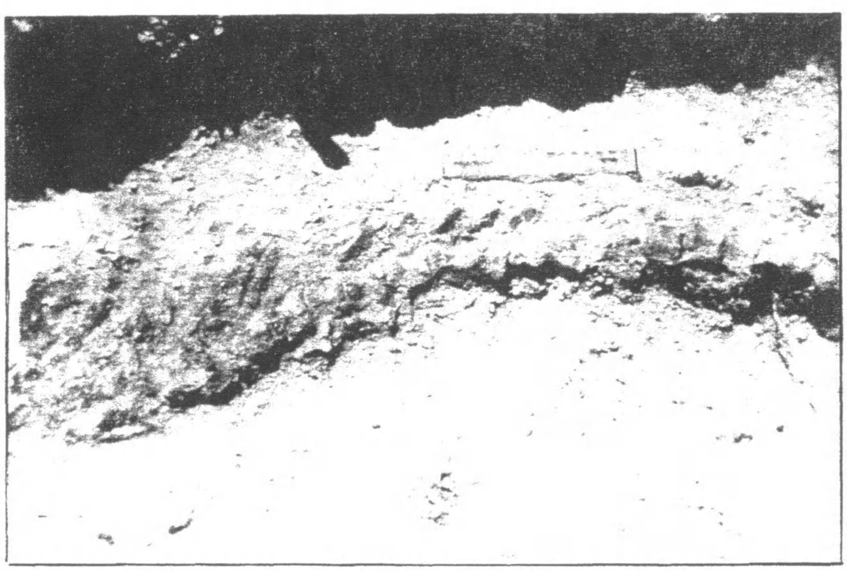


Figure 25--Articulated segment of 22 caudal vertebrae collected from Westside Quarry. Ruler is 30 cm.

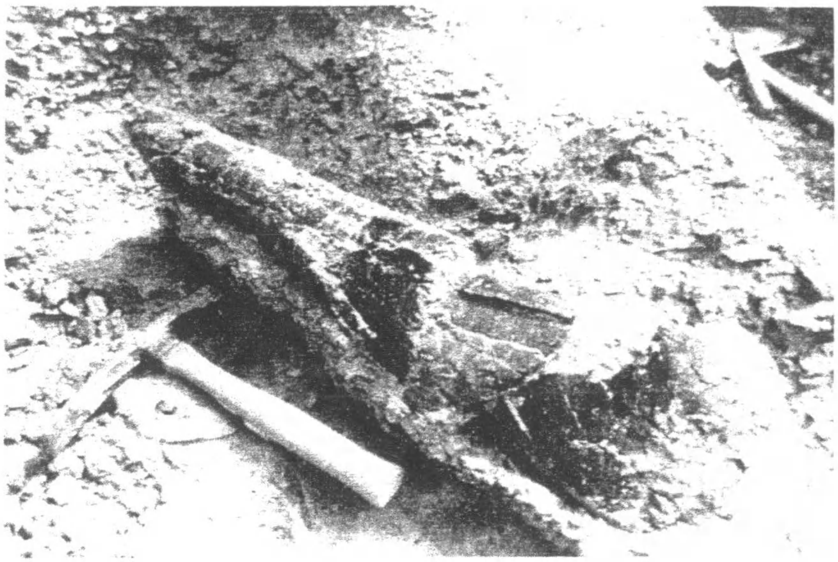


Figure 26--Partial limb bone crushed by diagenetic compaction within Westside Quarry.

As in the two Styracosaurus quarries, easily transported bones are under-represented in the Westside Quarry sample. Easily mobilized skeletal elements were probably winnowed by the same flood event that ultimately buried the bone bed. However, vertebrae, phalanges, and metapodials are considerably more common in Westside Quarry than in either Canyon Bone Bed or Dino Ridge Quarry (table 1, appendix #2). This relative abundance of vertebrae, phalanges, and metapodials is probably a result of the state of articulation of the bone bed at the time of exposure to current. Disarticulated vertebrae and phalanges would be readily transported by current, articulated vertebral sections, manus, and pes would not. Studies of disarticulation sequences in mammals indicate that vertebral sections and limb extremities are particularly resistant to disarticulation, especially under dry conditions (Toots, 1965; Hill, 1979). Therefore, it can be inferred that articulated vertebral segments and limb extremities were present when flooding and burial occurred. If conditions prior to burial were extremely dry, it is possible that the carcasses were partially mummified (Toots, 1965; Carpenter, 1987).

Skeletal elements in Westside Quarry were not abraded by current. All bones surfaces are smooth with no indication of surficial cracking or flaking. The orientation of bones in the quarry is predominately a result of bioturbation, and will be discussed under biologic modifications.

Biologic data--

Biologic constraints--Systematic description of the prosauralophan hadrosaurs preserved in Westside Quarry is not yet complete. An estimate based on the number of right dentaries and size variations in the sample indicates that at least four adult animals and one juvenile are present in the quarry. As with the other quarries, this estimate is tentative pending systematic description. In addition to the hadrosaur remains, one tiny lizard vertebra and one nodosaur tooth were discovered.

Biologic modifications--Articulated segments of vertebrae occur in Westside Quarry, all other skeletal elements in the bone bed are disarticulated (see plate 3, appendix #2). Skeletal elements within Westside Quarry are more closely associated than in either *Styracosaurus* quarry, although there are no direct bone to bone associations. The bones are crudely sorted. Large limb bones occur in the lower levels of the deposit, smaller skeletal elements and bone fragments occur scattered throughout the bone bed. Most linear skeletal elements within Westside Quarry are preferentially inclined at less than 10 degrees. The azimuth of the bones is random, and some bones are oriented in unstable, almost vertical positions (figure 27).

Non-diagenetic bone breakage is not as extensive in Westside Quarry as in the other two quarries. Many fragile skeletal elements are completely intact, and most dentaries possess undamaged tooth batteries. The minute scratch marks so prevalent in the Canyon Bone Bed sample are not present on Westside Quarry bones, perhaps the high clay content of the bone bed matrix inhibited surficial scratching. Tooth marks were not observed on any bones in the sample, although teeth shed from carnivorous dinosaurs were recovered.

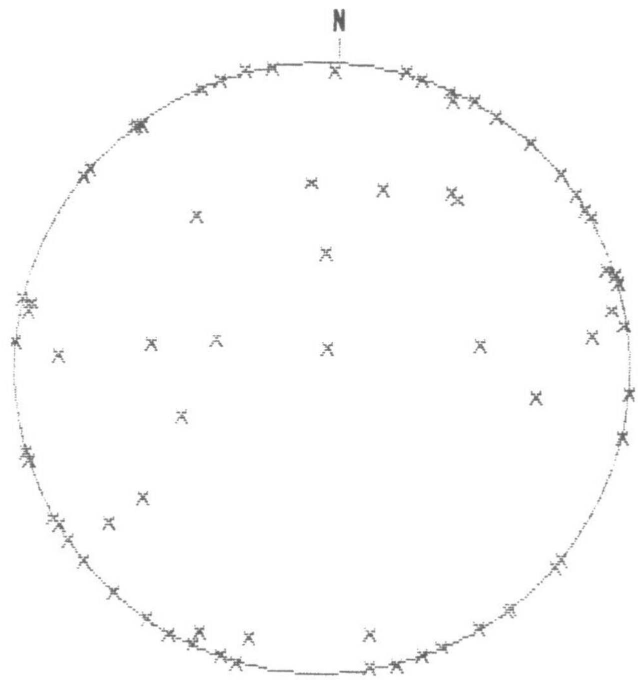


Figure 27--Lower-hemisphere stereographic projection (Schmidt net) of bone trend and plunge data for elongate skeletal elements in Westside Quarry. The azimuth of the bones is random, and most bones are inclined at less than ten degrees. Horizontal bones are plotted in both the northern and southern hemispheres. Total sample n = 46.

I propose that Westside Quarry was trampled and scavenged, but to a lesser extent than either Canyon Bone Bed or Dino Ridge Quarry. Considering the excellent state of preservation of many fragile bones, it is possible that the bone bed was bioturbated and trampled after burial, possibly after rewetting of the depression. In this case, the sedimentary matrix would have acted as a viscous cushion and considerably reduced breakage. Therefore, many of the isolated vertebrae and phalanges in the bone bed were probably disarticulated and dispersed by trampling after burial. The bones in unstable positions were upended by trampling and subsequently held in position as the matrix dried.

Taphonomic summary--

Canyon Bone Bed, Dino Ridge Quarry, and Westside Quarry preserve low-diversity, mass death assemblages of dinosaurs. Fossil bones in the three quarries consist primarily of skeletal lag elements (Voorhies, 1969; Lehman, 1982), thus all three bone beds are presumably nontransported (autochthonous). The similar weathering stages of the fossil bones within each quarry and the limited taxonomic diversity of the bone beds indicate that the three quarries are not attritional fossil accumulations (Behrensmeyer, 1978; Turnbull and Martill, 1988; Carpenter, 1989). In addition, there is absolutely no geologic evidence suggesting catastrophic mass mortality. Mortality was apparently neither attritional nor catastrophic (instantaneous), but probably occurred over a relatively short period of time (ie. one season, maybe one year) and thus can be classified as noncatastrophic mass mortality (Carpenter, 1988). Possible causes of mortality are deferred to the final section of this paper.

The animals in Canyon Bone Bed and Dino Ridge Quarry were buried in shallow, vegetated oxbow lakes; the animals in Westside Quarry were interred within and around what may have been an ephemeral floodplain water hole. Whether the animals died at the site of burial or were transported en masse as complete carcasses to the site of burial is difficult to determine. However, it seems improbable that disparate size classes of dinosaur carcasses (adults and juveniles) would be transported and deposited collectively. Furthermore, there is no indication in any quarry of a flood event of sufficient magnitude to transport numerous complete dinosaur carcasses. I believe that the above analyses indicate that the dinosaurs preserved in Canyon Bone Bed, Dino Ridge Quarry, and Westside Quarry died at or very near the site of eventual burial.

Carcasses in Canyon Bone Bed and Dino Ridge Quarry disarticulated subaqueously; disarticulation was expedited by trampling and occasional flood currents. Episodic floods repeatedly winnowed easily mobilized skeletal elements from Canyon Bone Bed and Dino Ridge Quarry. Most of the bones that remain in these two quarries are skeletal lag elements which defied current transport. These remaining bones were fragmented and scattered by bioturbation, and were eventually interred, possibly by trampling, into the soft bottom sediments of the oxbow lakes. The animals in Westside Quarry disarticulated under dry, subaerial conditions; some of their bones may have been held together in a partially mummified state. A single overbank flood event ultimately buried the bone assemblage. This same flood apparently winnowed easily transported skeletal elements from the quarry. After burial, Westside Quarry may have been re-saturated and trampled. All three bone beds were probably scavenged prior to burial. Scavengers may have heightened the degree of differential preservation in the quarries by carrying off or devouring small skeletal elements.

Following burial, Westside Quarry underwent pedogenesis; the calcic soils that characterize the Two Medicine eco-system were conducive to bone preservation (Gordon and Buikstra, 1981; White and Hannus, 1983). The relatively reduced Eh potential of the calcareous encasing matrices of Canyon Bone Bed and Dino Ridge Quarry was apparently also favorable for bone preservation. Fossil bones within all three quarries were slightly crushed by diagenetic compaction. Recent pedogenesis adversely affected the preservational state of many bones within Dino Ridge Quarry.

PART FOUR--DISCUSSION AND CONCLUSION

Thanatic considerations--

Reconstructing the thanatic factors (cause of death) responsible for the genesis of Canyon Bone Bed, Dino Ridge Quarry, and Westside Quarry is necessarily interpretive. As would be expected with noncatastrophic mass death assemblages, definitive criteria pointing irrevocably to the cause of death are not preserved in the rock record. Indeed, all three bone beds occur in rather typical alluvial sediments. Nevertheless, a theory can be synthesized by considering taphonomic and geologic data collected from the three sites in conjunction with modern ecologic information. I propose that the animals within all three bone beds perished during drought. Paleoclimatic data from the Two Medicine Formation certainly support an environmental setting prone to drought. The close association of the bone beds with caliche horizons and their occurrence within aqueous depositional settings are also indicative of drought-related mortality (Shipman, 1975). One additional factor supporting drought is the possible mummification of limb extremities and vertebral segments within Westside Quarry.

I envision the following sequence of events leading up to mass mortality. A severe drought occurred on the Two Medicine coastal plain. Consumable vegetation became scarce, and many floodplain water sources such as lakes, water holes, and ephemeral streams dried up. Groups or herds of Styracosaurus sp? gathered in the vicinity of remaining water sources (oxbow lakes) in order to forage and drink. For similar reasons, although many thousands of years earlier, a herd of prosauralophan hadrosaurs congregated around a floodplain water hole. The convergence of certain animal species around water sources during drought is well documented in modern ecosystems (Henshaw, 1972; Conybeare and Haynes, 1984; Behrensmeyer, 1981).

As the drought continued the animals became weaker, less mobile, and more dependent upon their limited, local supply of food and water. Overgrazing and trampling eventually decimated the food supply, and a large number of animals gradually perished as a result of starvation, malnutrition, and disease. Another alternative is that the water supply was depleted prior to the food supply. In this case, the regulation of body temperature and the excretion of soluble waste products would have been impaired (Runnells, 1954). Animals would have been susceptible to sunstroke (Carpenter, 1987), and may have been poisoned by a buildup of metabolites in their bodies. Those animals that died within or around the perimeter of the lakes/water hole underwent the taphonomic processes described in section three of this paper, and were ultimately buried and fossilized, thus becoming part of the fossil record.

Although I consider drought as the most probable cause of mortality, other alternatives must be addressed. Mortality due to volcanic activity or catastrophic mass-wasting can be ruled out as there is no supporting geologic evidence. A severe winter storm is also highly unlikely since the Cretaceous was evidently a period of considerable warmth, and most Cretaceous plants evolved in an environment seldom affected by freezing temperatures (Frakes, 1979; Wolfe and Upchurch, 1987). Mass death related to forest fire is improbable since fusinite is not preserved in any of the bone beds and because a mass death assemblage caused by a forest fire should preserve a diverse array of species that sought refuge in water (Sander, 1987). A fatal species-specific virus or a plague unrelated to drought is certainly a possibility, though I know of no way to test this hypothesis (Shipman, 1981).

A frequently proposed thanatic scenario for monospecific mass mortality assemblages is death by drowning in fluvial channels during floods (Koster, 1984; Koster and Currie, 1987; Turnbull and Martill, 1988; Wood, Thomas, and Visser, 1988; Dodson, 1971). This scenario has been suggested for mass death assemblages within channel sandstones, and for assemblages preserved in overbank sediments (titanothere bone bed, Turnbull and Martill, 1988; Styracosaurus Bonebed 91, Wood, Thomas, and Visser, 1988). Mass drowning during a flood cannot be ruled out for Canyon Bone Bed, Dino Ridge

Quarry, or Westside Quarry. However, in the case of Westside Quarry, I find the prospect of drowning numerous hadrosaurs in a stream channel, transporting their carcasses en masse downstream, floating their bodies out of the channel, and then depositing the carcasses collectively on the floodplain unlikely. It would presumably require a flood event of grand scale to convey numerous complete hadrosaur carcasses from a channel onto a floodplain. Also, it seems likely that some type of crude size sorting of carcasses should occur, with the smaller animals either transported farther downstream in the channel or farther out onto the floodplain. Furthermore, considering the magnitude of overbank flooding necessary to transport dinosaur carcasses and the high aggradation rates characteristic of the Two Medicine alluvial plain, at least partial burial of some animals should have occurred at the time of initial transport and deposition. Taphonomic data indicate that partial burial did not occur. As for Canyon Bone Bed and Dino Ridge Quarry, direct evidence supporting or refuting mass drowning and subsequent mass transport is lacking. My personal bias is to assume that fossil assemblages in low-energy depositional settings are probably autochthonous unless evidence exists to the contrary. It seems unnecessary to propose a mechanism to amass very large animals in an environment where they would probably congregate naturally.

Paleoecological implications--

Monospecific mass death assemblages should preserve gregarious species (Carpenter, 1988), therefore the styracosaurs in Canyon Bone Bed and Dino Ridge Quarry and the prosauralophan hadrosaurs in Westside Quarry were probably social, herding animals. Whether they were gregarious year-round, or only during the dry season cannot be determined. Many herding animals in Africa today disperse during the rainy season and reconvene during the dry season when food and water are in short supply (Western, 1975). Provided death was drought induced, I further conclude that the dinosaurs required access to free water during dry spells and thus were water-dependent. Elephants, zebra, buffalo, and wildebeest are examples of water-dependent species (Lamprey, 1963; Ayeni, 1975). Animals that are not water-dependent satisfy their water needs by selecting food with a high water content, such as flesh, blood, and certain types of browse (Ayeni, 1975).

Several alternatives seem plausible as to why the three bone beds under investigation are monospecific (or very nearly so in the case of Dino Ridge Quarry). First of all, water-independent species living on the Two Medicine coastal plain may have opted to stay away from densely populated water sources during the dry season, thereby avoiding competition for limited food and water resources. In addition, water-dependent dinosaur species, like some extant mammal species, may have utilized different dry season refuges, and in this manner minimized competition. Lamprey (1963) reported that in the Tarangire Game Reserve in Tanganyika, Africa, zebra and wildebeest migrate into separate areas during the dry season; zebra concentrate in open grassland, while the wildebeest congregate in woodlands. Partitioning of dry season resources by dinosaurs on the Two Medicine coastal plain could explain why the styracosaur death assemblages occur in lushly vegetated oxbow lake paleoenvironments while the hadrosaur death assemblage is associated with an ephemeral floodplain water hole. Trophic dynamics may have also played a role in this apparent ecological separation. Hadrosaurids had a wider vertical feeding range than ceratopsians (Farlow, 1976; Beland and Russell, 1978), and hence were able to feed upon a greater variety of vegetation. During a drought, hadrosaurs were probably able to procure a wider assortment of the remaining vegetation. The ceratopsians, with their more limited feeding capabilities, may have concentrated on marsh vegetation, such as is preserved in Canyon Bone Bed and Dino Ridge Quarry. Interestingly, Sternberg (1970) reported the occurrence of monospecific ceratopsian bone beds within sediments containing "rush impressions" in Alberta, Canada, and suggested that "at times ceratopsians congregated in certain swampy areas from which other animals were excluded."

Interspecific aggression and territorial behavior may have also been responsible for the monospecific nature of the three Landslide Butte bone beds. Ayeni (1975) observed that small species generally vacate a drinking site when larger species arrive, and Jarman (1972) reported that elephant and buffalo seemed to abstain from using the same watering site. Environmental stress may heighten aggressive or territorial behavior. Henshaw (1972) observed that elephants in the Yankari Game Reserve, Nigeria, became increasingly aggressive during the dry season, and often drove encroaching bovids away from their home range. Considering the large size and gregarious nature of the dinosaur species in question, interspecific aggression and effective territorial defense during environmentally stressful periods is certainly possible (Farlow and Dodson, 1975). One final alternative is that highly selective mortality, as opposed to ecological segregation, resulted in the low-diversity bone beds. A diverse array of species may have frequented Canyon Bone Bed, Dino Ridge Quarry, and Westside Quarry, but only select species, those least capable of coping with the adverse conditions, fell victim to the drought.

Conclusion--

The Late Cretaceous (Campanian) Two Medicine Formation of northwestern Montana provides an excellent opportunity to investigate dinosaur evolution, paleoecology, and behavior. Tectonic and paleoclimatic circumstances during deposition of the formation interacted constructively to create optimum conditions for fossil preservation. Rapid subsidence rates and associated high aggradation rates constrained the lateral migration of stream channels on the Two Medicine coastal plain (Kraus and Middleton, 1987; Alexander and Leeder, 1987), and high sedimentation rates induced the rapid burial of many surface bone assemblages. Thus, bones were rapidly buried and seldom reworked or transported by migrating stream channels. In addition, the prevailing climate produced calcic soils which were conducive to bone preservation.

Tectonic and paleoclimatic conditions also created a very dynamic, and sometimes very harsh paleoenvironmental setting. Tectonically driven marine transgressions episodically caused dramatic reductions in aerial habitat on the Two Medicine coastal plain (Horner, 1984). Drought conditions also affected the Two Medicine ecosystem. Animals living on the Two Medicine coastal plain either developed strategies to cope with these environmental circumstances, or, as is evidenced by this study, perished.

REFERENCES

Alexander, J. and Leeder, M. R., 1987, Active tectonic control on alluvial architecture, in F. G. Ethridge and R. M. Flores (eds.), Recent Developments in Fluvial Sedimentology: Society of Economic Paleontologists and Mineralogists Special Publication 39, p. 243 - 252.

Andere, D. K., 1981, Wildebeest Connochaetes taurinus (Burchell) and its food supply in Amboseli Basin: Afr. J. Ecol., vol. 19, p. 239 - 250.

Ayeni, J. S. O., 1975, Utilization of waterholes in Tsavo National Park (East): E. Afr. Wildl. J., vol. 13, p. 305 - 323.

Behrensmeyer, A. K., 1978, Taphonomic and ecologic information from bone weathering: Paleobiology, vol. 4, no. 2, p. 150 - 162.

____________________, 1981, Vertebrate paleoecology in a Recent East African ecosystem, Pp. 591 - 615, in J. Gray, A. J. Boucot, and W. B. N. Berry (eds.)., Communities of the Past: Hutchinson Ross Pub. Co., Stroudsburg. PA, 623 p.

____________________, 1984, The bones of Amboseli Park as a key to East African paleoecology, in P. H. Oehser (ed., et al.), On research and exploration projects supported by the National Geographic Society, for which an initial grant or continuing support was provided for the year 1975: Research Reports-National Geographic Society, 16, p. 91 - 109.

Behrensmeyer, A. K., Western, D., and Dechant Boaz, D. E., 1979, New perspectives in vertebrate paleoecology from a recent bone assemblage: Paleobiology, vol. 5, no. 1, p. 12 - 21.

Behrensmeyer, A. K., Gordon, K. D., and Yanagi, G. T., 1986, Trampling as a cause of bone surface damage and pseudo-cutmarks: Nature, vol. 319, p. 768 - 771.

Beland, P., and Russell, D. A., 1978, Paleoecology of Dinosaur Provincial Park (Cretaceous), Alberta, interpreted from the distribution of articulated vertebrate remains: Can. J. Earth Sci., vol. 15, p. 1012 - 1024.

Carpenter, K., 1987a, Paleoecological significance of droughts during the Late Cretaceous of the western interior, Pp. 42 - 47, In P. J. Currie and E. H. Koster (eds.)., Mesozoic Terrestrial Ecosystems: Occasional Papers of the Tyrell Museum of Paleontology, no. 3, 235 p.

______________, 1987b, Potential for fossilization in Late Cretaceous - Early Tertiary swamp environments: Geol. Soc. Am. Abstr., Rocky Mtn. Section, 40th an., p. 264.

______________, 1988, Dinosaur bone beds and mass mortality: implications for the K - T extinction (abs.): Lunar and Planetary Institute Contribution 673, p. 24 - 25.

______________, 1989, Dinosaur bone beds and mass mortality: implications for the Cretaceous - Tertiary extinction: Global Catastrophes, Lunar and Planetary Institute (in press)

Chadwick, R. A., 1981, Chronology and structural setting of volcanism in southwestern and central Montana: Montana Geol. Soc. Guidebook, 1981 Field Conference Southwest Montana, p. 301 - 310.

Cobban, W. A., 1955, Cretaceous rocks of northwestern Montana: Billings Geol. Soc. Guidebook, sixth annual field conference, p. 107 - 119.

Conybeare, A., and Haynes, G., 1984, Observations on elephant mortality and bones in water holes: Quat. Res., vol. 22, p. 189 - 200.

Corfield, T. F., 1973, Elephant mortality in Tsavo National Park, Kenya: E. Afr. Wildl. J., vol. 11, p. 339 - 368.

Crabtree, D. R., 1987, Angiosperms of the northern Rocky Mountains: Albian to Campanian (Cretaceous) megafossil floras: Ann. Missouri Bot. Gard., vol. 74, p. 707 - 747.

Currie, P. J., 1982, Hunting dinosaurs in Alberta's huge bonebed: Canadian Geographic, vol. 10, no. 4, p. 34 - 39.

Currie P. J., and Dodson, P., 1984, Mass death of a herd of ceratopsian dinosaurs, in W. E. Reif and F. Westphal, (eds.), Short Pap. Third Symposium on Mesozoic Terrestrial Ecosystems, Tubingen, 1984, p. 61 - 66.

Dodson, P., 1971, Sedimentology and taphonomy of the Oldman Formation (Campanian), Dinosaur Provincial Park, Alberta (Canada): Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 10, p. 21 - 74.

Farlow, J. O., 1976, A consideration of the trophic dynamics of a Late Cretaceous large-dinosaur community (Oldman Formation): Ecology, vol. 57, p. 841 - 857.

Farlow, J. O., and Dodson, P., 1975, The behavioral significance of frill and horn morphology in ceratopsian dinosaurs: Evolution, vol. 29, p. 363 - 361.

Frakes, L. A., 1979, Climate throughout geologic time: Elsevier Sci. Pub. Co., New York, 310 p.

Gavin, W. M. B., 1986, A paleoenvironmental reconstruction of the Cretaceous Willow Creek Anticline dinosaur nesting locality: north central Montana: Unpublished Masters Thesis, Montana State University, 148 p.

Gifford, D. P., 1985, Taphonomic specimens, Lake Turkana: in J. S. Lea, (ed., et al.), On research and exploration projects supported by the National Geographic Society, for which an initial grant or continuing support was provided in the year 1976: Research Reports-National Geographic Society, 17, p. 419 - 428.

Gifford, D. P., and Behrensmeyer, A. K., 1977, Observed formation and burial of a recent human occupation site in Kenya: Quat. Res., vol. 8, p. 245 - 266.

Gilmore, C. W., 1914, A new ceratopsian dinosaur from the Upper Cretaceous of Montana, with a note on Hypacrosaurus: Smithsonian Miscellaneous Collections, vol. 43, no. 3, p. 1 - 10.

______________, 1917, Brachyceratops, a ceratopsian dinosaur from the Two Medicine Formation of Montana, with notes on associated fossil reptiles: U.S.G.S. Prof. Paper 103, p. 1 - 45.

______________, 1922, The smallest known horned dinosaur, Brachyceratops: Proceedings of the U.S. Natl. Mus., vol. 61, no. 3, p. 1 - 7.

______________, 1929, Hunting dinosaurs in Montana: Explorations and field work of the Smithsonian Institution in 1928: p. 7 - 12.

_______________, 1930, On dinosaurian reptiles from the Two Medicine Formation of Montana: Proceedings of the U.S. Natl. Mus., vol. 77, no. 16, p. 1 - 39.

_______________, 1937, On the detailed skull structure of a crested hadrosaurian dinosaur: Proceedings of the U.S. Natl. Mus., vol. 84, no. 3023, p. 481 - 491.

_______________, 1939, Ceratopsian dinosaurs from the Two Medicine Formation, Upper Cretaceous of Montana: Proceedings of the U.S. Natl. Mus., vol. 87, no. 3066, p. 1 - 18.

Gill, J. R., and Cobban, W. A., 1973, Stratigraphy and geologic history of the Montana Group and equivalent rocks, Montana, Wyoming, and North and South Dakota: U.S.G.S. Prof. Paper 776, 37 p.

Gordon, C. C., and Buikstra, J. E., 1981, Soil pH, bone preservation, and sampling bias at mortuary sites: American Antiquity, vol. 46, no. 3, p. 566 - 571.

Habicht, J. K. A., 1980, Paleoclimate, paleomagnetism, and continental drift: Amer. Assoc. Petrol. Geol., Studies in Geology no. 9, 31 p.

Hare, P. E., 1980, Organic geochemistry of bone and its relation to the survival of bone in the natural environment, Pp. 208 - 219, in A. K. Behrensmeyer and A. P. Hill (eds.), Fossils in the Making: Vertebrate Taphonomy and Paleoecology: The University of Chicago Press, Chicago, 338 p.

Haynes, G., 1980, Evidence of carnivore gnawing on Pleistocene and Recent mammalian bones: Paleobiology, vol. 6, no. 3, p. 341 - 351.

Henshaw, J., 1972, Notes on conflict between elephants and some bovids and on other inter-specific contacts in Yankari Game Reserve, N. E. Nigeria: E. Afr. Wildl. J., vol. 10, p. 151 - 153.

Hill, A., 1979, Disarticulation and scattering of mammal skeletons: Paleobiology, vol. 5, no. 3, p. 261 - 274.

Hillman, J. C., and Hillman, A. K. K., 1977, Mortality of wildlife in Nairobi National Park, during the drought of 1973-1974: E. Afr. Wildl. J., vol. 15, p. 1 - 18.

Horner, J. R., 1982, Evidence of colonial nesting and site fidelity among ornithischian dinosaurs: Nature, vol. 297, p. 675 - 676.

______________, 1984, Three ecologically distinct vertebrate faunal communities from the Late Cretaceous Two Medicine Formation of Montana, with discussion of evolutionary pressures induced by interior seaway fluctuations: Mont. Geol. Soc. 1984 Field Conf. and Symposium Guidebook, p. 299 - 303.

______________, 1988, Cranial allometry of _Maiasaura peeblesorum_ (Ornithischia; Hadrosauridae) and its behavioral significance: Jour. of Vert. Paleo. (abstr.), vol. 8, supplement to no. 3, p. 18A.

Horner, J. R., and Makela, R., 1979, Nest of juveniles provides evidence of family structure among dinosaurs: Nature, vol. 282, p. 296 - 298.

Horner, J. R., and Weishampel, D. B., 1988, A comparative embryological study of two ornithischian dinosaurs: Nature (London), 332 (6161), p. 256 - 257.

Jarman, P. J., 1972, The use of drinking sites, wallows and salt licks by herbivores in the flooded Middle Zambezi Valley: E. Afr. Wildl. J., vol. 10, p. 193 - 209.

Jerzykiewicz, T., and Sweet, A. R., 1988, Sedimentological and palynological evidence of regional climatic changes in the Campanian to Paleocene sediments of the Rocky Mountain Foothills, Canada: Sedimentary Geology, vol. 59, p. 29 - 76.

Jordan, T. E., 1981, Thrust loads and foreland basin evolution, Cretaceous, western United States: Amer. Assoc. Petrol. Geol. Bull., vol. 65, no. 12, p. 2506 - 2520.

Koster, E. H., 1984, Sedimentology of a foreland coastal plain; Upper Cretaceous Judith River Formation at Dinosaur Provincial Park: Can. Soc. of Pet. Geol., Field Trip Guidebook, 115 p.

______________, 1987, Vertebrate taphonomy applied to the analysis of ancient fluvial systems, _in_ F. G. Ethridge and R. M. Flores (eds.), Recent Developments in Fluvial Sedimentology: Society of Economic Paleontologists and Mineralogists Special Publication 39, p. 159 - 168.

Koster, E. H., and Currie, P. J., 1987, Upper Cretaceous coastal plain sediments at Dinosaur Provincial Park, southeast Alberta: Geol. Soc. Amer. Centennial Field Guide--Rocky Mountain Section, p. 9 - 14.

Kraus, M. J., and Middleton, L. T., 1987, Contrasting architecture of two alluvial suites in different structural settings, in F. G. Ethridge and R. M. Flores (eds.), Recent Developments in Fluvial Sedimentology: Society of Economic Paleontologists and Mineralogists Special Publication 39, p. 253 - 262.

Lamprey, H. F., 1963, Ecological separation of the large mammal species in the Tarangire Game Reserve, Tanganyika: E. Afr. Wildl. J., vol. 1, p. 63 - 92.

Langbein, W. B., and Schumm, S. A., 1982, Yield of sediment in relation to mean annual precipitation, in J. B. Laronne and M. P. Mosley (eds.), Erosion and Sediment Yield: Benchmark Papers in Geology, Hutchinson Ross Pub. Co., Stroudsburg, PA, p. 181 - 189.

Lawton, R., 1977, Taphonomy of the dinosaur quarry, Dinosaur National Monument. Univ. Wyo. Contrib. Geol., vol. 15, p. 119 - 126.

Lehman, T. M., 1982, A ceratopsian bone bed from the Aguja Formation (Upper Cretaceous) Big Bend National Park, Texas: Unpublished Masters Thesis, University of Texas, Austin, 210 p.

Lorenz, J. C., 1981, Sedimentary and tectonic history of the Two Medicine Formation, Late Cretaceous (Campanian), northwestern Montana: Unpublished PhD Dissertation, Princeton University, 215 p.

Lorenz, J. C., and Gavin, W., 1984, Geology of the Two Medicine Formation and the sedimentology of a dinosaur nesting ground: Montana Geol. Soc. 1984 Field Conf. and Symposium Guidebook, p. 175 - 186.

McLean, J. R., and Jerzykiewicz, T., 1978, Cyclicity, tectonics and coal: some aspects of fluvial sedimentology in the Brazeau-Paskapoo Formations, Coal Valley area, Alberta, Canada in A. D. Miall (ed.), Fluvial Sedimentology: Canadian Society of Petroleum Geologists Memoir 5, p. 441 - 468.

Retallack, G., 1985, Laboratory exercises in paleopedology: University of Oregon, Eugene, 74 p.

Runnells, R. A., 1954, Animal Pathology: The Iowa State College Press, Ames, Iowa, 718 p.

Russell, L. S., 1970, Correlation of the Upper Cretaceous Montana Group between southern Alberta and Montana: Can. Jour. Earth Sci., vol. 7, p. 1099 - 1108.

Sander, P. M., 1987, Taphonomy of the Lower Permian Geraldine Bonebed in Archer County, Texas: Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 61, p. 221 - 236.

Sanford, S., 1979, Towards a definition of drought, Pp. 33 - 40, in M. T. Hinchey (ed.), Proceedings of the Symposium on Drought in Botswana: The Botswana Society, Gaborone, Botswana, 305 p.

Schmidt, R. G., 1966, Source for Late Cretaceous volcanic breccia in west-central Montana (abstr.): U.S.G.S. Prof. Paper 550-A, p. 76.

________________, 1972, Geologic map of the Wolf Creek quadrangle, Lewis and Clark County, Montana: U.S. Geol. Survey Map GQ-974.

Shipman, P., 1975, Implications of drought for vertebrate fossil assemblages: Nature, vol. 257, no. 5528, p. 667 - 668.

____________, 1981, The life history of a fossil, an introduction to taphonomy and paleoecology: Harvard University Press, Cambridge, Mass., 222 p.

Skarpe, C., and Bergstrom, R., 1986, Nutrient content and digestibility of forage plants in relation to plant phenology and rainfall in the Kalahari, Botswana: Journal of Arid Environments, vol. 11, p. 147 - 164.

Stashchuk, M. F., 1972, The oxidation - reduction potential in geology: Consultants Bureau, New York, 121 p.

Stebinger, E., 1914, The Montana Group of northwestern Montana: U.S.G.S. Prof. Paper 90-G, p. 60 - 68.

_______________, 1916, Geology and coal resources of Teton County, Montana: U.S.G.S. Bull. 621-K, p. 117 - 156.

_______________, 1917, Stratigraphy of the Two Medicine Formation: U.S.G.S. Prof. Paper 103, p. 1 - 3.

Sternberg, C. M, 1970, Comments on dinosaurian preservation in the Cretaceous of Alberta and Wyoming: Natl. Mus. Can. Publ. Palaeontol., no. 4, 9 p.

Tannehill, I. R., 1947, Drought: Its causes and effects: Princeton University Press, Princeton, NJ, 264 p.

Toots, H., 1965, Sequence of disarticulation in mammalian skeletons: Univ. Wyo. Contrib. Geol., vol. 4, p. 37 - 39.

Treshow, M., 1970, Environment and plant response: McGraw-Hill Inc., New York, 422 p.

Tucker, M. E., 1981, Sedimentary petrology, an introduction: Blackwell Scientific Publications, London, 252 p.

Turnbull, W. D, and Martill, D. M., 1988, Taphonomy and preservation of a monospecific titanothere assemblage from the Washakie Formation (Late Eocene), Southern Wyoming. An ecological accident in the fossil record: Palaeogeograpy, Palaeoclimatology, Palaeoecology, vol. 63, p. 91 - 108.

Vaadia, Y., and Waisel, Y., 1967, Physiological processes as affected by water balance. in R. M. Hagan et al. (eds.), Irrigation of Agricultural Lands: Amer. Soc. Agron., Madison, Wisconsin, p. 354 - 372.

Viele, G. W., and Harris, F. G. II, 1965, Montana Group stratigraphy, Lewis and Clark County, Montana: Amer. Assoc. Petrol. Geol. Bull., vol. 49, p. 379 - 417.

Voorhies, M. R., 1969, Taphonomy and population dynamics of an Early Pliocene vertebrate fauna, Knox County, Nebraska: Univ. Wyo. Contrib. Geol. Spec. Pap. 1, 69 p.

Western, D., 1975, Water availability and its influence on the structure and dynamics of a savannah large mammal community: E. Afr. Wildl. J., vol. 13, p. 265 - 286.

White, E. M., and Hannus, L. A., 1983, Chemical weathering of bone in archaeological soils: American Antiquity, vol. 48, no. 2, p. 316 - 322.

Winkler, D., et al., 1988, The Proctor Lake dinosaur locality, Lower Cretaceous of Texas: Hunteria, vol. 2, no. 2, 8 p.

Wolfe, J. A., and Upchurch, G. R., 1987, North American nonmarine climates and vegetation during the Late Cretaceous: Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 61, p. 33 - 77.

Wood, R. C., 1988, A monospecific death assemblage of fossil side-necked turtles from the Cretaceous of Brazil (abstr.): International Symposium on Vertebrate Behavior as Derived from the Fossil Record, Museum of the Rockies, Bozeman, Montana, p. 17.

Wood, J., Thomas, R., and Visser, J., 1988, Fluvial processes and vertebrate taphonomy: the Upper Cretaceous Judith River Formation, south-central Dinosaur Provincial Park, Alberta, Canada: Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 66, p. 127 - 143.

APPENDIX #1

BONE BED MEASURED SECTIONS

CANYON BONEBED MEASURED SECTION

UNIT	INTERVAL (CM)	LITHOLOGIC DESCRIPTION
1	0 - 93	5GY 5/1, GREENISH-GREY SILTY MUDSTONE, FRIABLE, SHALEY PARTING, MINUTE RED MOTTLES, ABUNDANT CALICHE NODULES (2-5 cm. dia.), SOME REMNANT HORIZONTAL LAMINATIONS, CALCAREOUS, BASE NOT EXPOSED, SHARP UPPER CONTACT.
2	93 - 108	VERY FINE GRAINED SILTSTONE, WELL SORTED, HORIZONTALLY LAMINATED, SURFACE EXTENSIVELY BURROWED (HORIZONTAL AND VERTICAL BURROWS), BURROWS ARE INFILLED BY SIMILAR FINE GRAINED SILTSTONE, WEATHERS REDDISH BROWN, CALCAREOUS, SHARP UPPER CONTACT.
3	108 - 152	5GY 4.5/1, GREY SILTY MUDSTONE, MASSIVE, POORLY INDURATED, VERY FRIABLE, CONTAINS REMAINS OF SMALL FRESHWATER INVERTEBRATES, CALCAREOUS, SHARP UPPER CONTACT.
4	152 - 230	5Y 2.5/2, OLIVE GREEN BENTONITE, MASSIVE, "POPCORN" TEXTURE ON WEATHERED SURFACES, HEXAGONAL BIOTITE CRYSTALS, NON-CALCAREOUS, SHARP UPPER CONTACT.
5	230 - 300	5GY 4.5/1, GREY-GREEN SILTY MUDSTONE, MASSIVE, FRIABLE, BLOCKY, CALCAREOUS, SHARP UPPER CONTACT.
6	300 - 425	5GY 5/1, DARK GREY SILTY MUDSTONE, MASSIVE, VERY NODULAR IN LOWER PORTIONS, SOME VERY LARGE (10 cm. OR MORE) CALICHE NODULES, BLOCKY PARTING, FRIABLE, CALCAREOUS, SHARP UPPER CONTACT.
7	425 - 451	5GY 5/1, GREY-GREEN SILTY MUDSTONE, MASSIVE, FRIABLE, SHALEY PARTING, ABUNDANT SMALL CALICHE NODULES AT BASE, CALCAREOUS, SHARP UPPER CONTACT.

8	451 - 476	LIGHT GREY SILTSTONE, HORIZONTALLY LAMINATED, WELL SORTED SILT WITH CLAY MATRIX, FAIRLY WELL INDURATED, SLIGHTLY CALCAREOUS, GRADATIONAL UPPER CONTACT.
9	476 - 608	5GY 4/1, DARK GREY-GREEN MUDSTONE, MASSIVE, VERY FRIABLE, BLOCKY PARTING, CALCAREOUS, SHARP UPPER CONTACT.
10	608 - 624	SAME AS UNIT 8.
11	624 - 768	5GY 4.5/1, GREY-GREEN SILTY MUDSTONE, MASSIVE, CALCAREOUS, SHARP UPPER CONTACT.
12	768 - 976	5GY 4.5/1, GREY-GREEN SILTY MUDSTONE, MASSIVE, VERY NODULAR AT BASE, APPROXIMATELY 10 cm. OF COALESCED NODULES AT BASE, NODULES SMALL-MEDIUM SCALE, NODULES ABSENT IN UPPER PORTIONS, BLOCKY PARTING, SURFACE WEATHERS TO A "POPCORN" TEXTURE WITH A WHITE POWDERY CRUST, CALCAREOUS, GRADATIONAL UPPER CONTACT.
13	976 - 1203	5GY 4.5/1, GREY-GREEN SILTY MUDSTONE, MASSIVE, FRIABLE, BLOCKY PARTING, CALCAREOUS, GRADATIONAL (MOSTLY OBSCURED) UPPER CONTACT.
14	1203 - 1319	5GY 4.5/1, GREY-GREEN SILTY MUDSTONE, MASSIVE, FRIABLE, BLOCKY PARTING, CALCAREOUS, SHARP EROSIONAL UPPER CONTACT.
15	1319 - 1637	GREY SANDSTONE, FINE-MEDIUM GRAINED, WELL SORTED, DIFFERENTIALLY CEMENTED, CALCAREOUS CEMENT, MEDIUM SCALE (20 cm) TROUGH CROSS-BEDDING AT BASE, SMALL SCALE (1-2 cm.) RIPPLE CROSS-BEDDING AT TOP OF UNIT, BURROWED BEDDING IS CONTORTED AROUND BURROWS, SHARP UPPER CONTACT.

16	1637 - 1667	2.5Y 4/2 DRY, 2.5Y 3/2 WET, DARK BROWN MUDDY SILTSTONE, EXTREMELY FOSSILIFEROUS, CONTAINS THE REMAINS OF STYRACOSAURUS, CARBONIZED PLANT MATERIAL, AND FRESHWATER INVERTEBRATES, VERY SHARP UPPER AND LOWER CONTACTS, BED VARIES IN THICKNESS THROUGHOUT QUARRY EXPOSURE (23 - 30 cm.), BLOCKY PARTING, FRIABLE, CALCAREOUS, VERY SHARP UPPER CONTACT.
17	1667 ------	5GY 5/1 DRY, 5GY 4/1 WET, LIGHT GREY-GREEN SILTSTONE, MASSIVE WELL SORTED, BLOCKY PARTING, FRIABLE, CONTAINS FRESHWATER INVERTEBRATES, DEVOID OF FOSSIL BONE, NO DISCERNABLE SEDIMENTARY STRUCTURES, CONTAINS RARE SMALL CALICHE NODULES, CALCAREOUS, TOP NOT EXPOSED.

DINO RIDGE QUARRY MEASURED SECTION

UNIT	INTERVAL (CM)	LITHOLOGIC DESCRIPTION
1	0 - 140	5Y 4/1, GREY-BROWN MUDSTONE, MASSIVE, FRIABLE, SHALEY PARTING, LARGE CALICHE NODULES NEAR UPPER CONTACT, SLIGHTLY CALCAREOUS, BASE NOT EXPOSED, EROSIONAL UPPER CONTACT.
2	140 - 154.	GREY SANDSTONE, VERY FINE GRAINED, WELL SORTED, RIPPLE CROSS-LAMINATION (1/2-2 cm.), HORIZONTAL LAMINATIONS, WEATHERS REDDISH-BROWN, CALCAREOUS, GRADATIONAL UPPER CONTACT.
3	154 - 184	5GY 5/1, GREY-GREEN MUDSTONE, MASSIVE, FRIABLE, SHALEY PARTING, CALCAREOUS SHARP EROSIONAL UPPER CONTACT.
4	184 - 209	GREY SANDSTONE, VERY FINE-MEDIUM GRAINED, POORLY SORTED, SUBANGULAR, MUD RIP-UPS AT BASE, RIPPLE CROSS-LAMINATED (1 cm.), CALCAREOUS, GRADATIONAL UPPER CONTACT.
5	209 - 282	5GY 5/1, GREY SILTY MUDSTONE, MASSIVE, FRIABLE, SHALEY PARTING, VERY POOR OUTCROP, CALCAREOUS, SHARP UPPER CONTACT.
6	282 - 307	ORANGISH-BROWN (WEATHERED) CALICHE, MASSIVE, GREY WHEN FRESH, VERY NODULAR, VERY CALCAREOUS, VARIES IN THICKNESS, GRADATIONAL UPPER CONTACT.
7a	307 - 389	5GY 5/1, GREENISH-GREY SILTY MUDSTONE, MASSIVE, SLIGHTLY MOTTLED, FOSSILIFEROUS, FRESHWATER BIVALVES AND GASTROPODS, ABUNDANT SMALL CALICHE NODULES AT BASE, OCCASIONAL ROOT CASTS, INCREASINGLY INDURATED AND SILTIER NEAR TOP, POOR OUTCROP, CALCAREOUS, GRADATIONAL UPPER CONTACT.

7b	389 - 517	GREY SILTSTONE, HORIZONTALLY LAMINATED, FOSSILIFEROUS, FRESHWATER INVERTEBRATES, POOR EXPOSURE, CALCAREOUS, SHARP UPPER CONTACT.
7c	517 - 637	5GY 6/1, GREEN SILTY MUDSTONE, MASSIVE, VERY FOSSILIFEROUS, LARGE FRESHWATER GASTROPODS, BIVALVES, AND PLANT MATERIAL, LESS FOSSILIFEROUS TO NON-FOSSILIFEROUS AT TOP, SILTIER AT TOP, LARGE MUD CLASTS AT BASE, SMALL MUD CLASTS THROUGHOUT, POOR OUTCROP, CALCAREOUS, GRADATIONAL UPPER CONTACT.
7d	637 - 682	LIGHT GREY SILTSTONE, MASSIVE, CALCAREOUS, GRADATIONAL UPPER CONTACT.
7e	682 - 712	5GY 4/1, DARK GREY MUDSTONE, MASSIVE, FRIABLE, BLOCKY PARTING, VERY POOR EXPOSURE, NON-CALCAREOUS, UPPER CONTACT SHARP, DEFINED BY COLOR CHANGE.
7f	712 - 861	5Y 6/1 - 5GY 6/1, LIGHT GREY SILTY MUDSTONE, MASSIVE, FRIABLE, BLOCKY PARTING, NON-CALCAREOUS, SHARP UPPER CONTACT.
8	861 - 937	5Y 3/2, DRAB OLIVE-GREY BENTONITE, MASSIVE, VARIABLE THICKNESS, WEATHERS TO A "POPCORN" TEXTURE, NON-CALCAREOUS, SHARP UPPER CONTACT.
9	937 - 1063	GREY SANDSTONE, FINE GRAINED, POORLY SORTED, DIFFERENTIALLY CEMENTED, 3 SLOPES, 3 LEDGES, LARGE SCALE CROSS-BEDS AT BASE OF CHANNEL (20 - 40 CM.), RIPPLE SCALE CROSS-LAMINATION AT TOP OF UNIT, CALCAREOUS, GRADATIONAL UPPER CONTACT.
10	1063 - 1186	5GY 5/1, LIGHT GREY SILTY MUDSTONE, MASSIVE, FRIABLE, SHALEY PARTING, DEEPLY WEATHERED, CALCAREOUS, SHARP UPPER CONTACT.

11	1186 - 1212	GREY SANDSTONE, FINE GRAINED, WELL SORTED, RIPPLE CROSS-LAMINATION (1 cm.), CALCAREOUS, SHARP UPPER CONTACT.
12a	1212 - 1266	5GY 4/1, GREY-GREEN MUDSTONE, MASSIVE, FRIABLE, SHALEY PARTING, VERY NODULAR, ROOT CASTS, CALCAREOUS, SHARP UPPER CONTACT.
12b	1266 - 1353	LIGHT GREY SILTSTONE, MASSIVE, FOSSILIFEROUS, CONTAINS REMAINS OF FRESHWATER INVERTEBRATES, CALCAREOUS, SHARP UPPER CONTACT.
12c	1353 - 1421	5Y 4/1, GREY MUDSTONE, MASSIVE, VERY FRIABLE, BLOCKY AND SHALEY PARTING, POOR OUTCROP, SLIGHTLY CALCAREOUS, SHARP UPPER CONTACT.
12d	1421 - 1492	LIGHT GREY SILTSTONE, MASSIVE, CONTAINS SMALL CLAY CLASTS, CALCAREOUS, SHARP UPPER CONTACT.
12e	1492 - 1507	CALICHE LAYER, MASSIVE, HARD INDURATED CALCIUM CARBONATE LAYER, GREY ON FRESH SURFACE, WEATHERS REDDISH-BROWN, VERY CALCAREOUS, GRADATIONAL UPPER CONTACT.
12f	1507 - 1631	5GY 5/1, GREY-GREEN MUDSTONE, VERY POOR EXPOSURE, CALICHE NODULES CONCENTRATED AT BASE, SHARP EROSIONAL UPPER CONTACT.
13	1631 - 1690	GREY SANDSTONE, FINE GRAINED, POORLY SORTED, BASAL LAG OF MUD RIP-UPS, PRIMARILY HORIZONTALLY LAMINATED (1 mm. - 1 cm.), EXTENSIVELY BURROWED AND BIOTURBATED, SHARP UPPER CONTACT.
14a	1690 - 1812	5GY 4/1, DARK GREY MUDSTONE, MASSIVE, FRIABLE, BLOCKY PARTING, SLIGHTLY CALCAREOUS, SHARP UPPER CONTACT.
14b	1812 - 1860	5Y 6.5/1, LIGHT GREY SILTY MUDSTONE, MASSIVE, FRIABLE, BLOCKY PARTING, SLIGHTLY NODULAR AT BASE, A FEW ROOT CASTS, CALCAREOUS, SHARP UPPER CONTACT.

14c	1860 - 1970	5Y 5/3 (5Y 5/2 FOR INDURATED LAYER), DARK GREY MUDSTONE, MASSIVE, FRIABLE, BLOCKY PARTING, WITHIN THIS UNIT IS A 15 cm. THICK INDURATED HORIZON THAT IS VERY CALCAREOUS, OVERALL UNIT IS SLIGHTLY CALCAREOUS, SHARP UPPER CONTACT.
15	1970 - 2043	GREY SANDSTONE, FINE GRAINED, WELL SORTED, MEDIUM-LARGE SCALE CROSS-STRATIFICATION AT BASE (20-25 cm.), RIPPLE CROSS-LAMINATION AND PLANAR LAMINATION AT TOP OF UNIT, CALCAREOUS, GRADATIONAL UPPER CONTACT.
16	2043 - 2153	BROWNISH-GREY MUDDY SILTSTONE, MASSIVE, POORLY SORTED, POORLY INDURATED, VERY FOSSILIFEROUS, ABUNDANT _STYRACOSAURUS_ BONES IN LOWER 30-35 cm. OF UNIT, ABUNDANT FRESHWATER INVERTEBRATES AND PLANT MATERIAL THROUGHOUT UNIT, FRIABLE, BLOCKY PARTING, CALCAREOUS, LOCATED ON TOP OF BUTTE, AFFECTED BY RECENT SOIL DEVELOPMENT.

WESTSIDE QUARRY MEASURED SECTION

UNIT	INTERVAL (CM)	LITHOLOGIC DESCRIPTION
1	0 - 15	10R 3/2 (RED), 5GY 5/1 (GREEN), RED-GREY MOTTLED SILTY MUDSTONE, MASSIVE, VERY FRIABLE, SHALEY PARTING, MOTTLING APPEARS HORIZONTAL IN TREND, CALCAREOUS, BASE NOT EXPOSED, GRADATIONAL UPPER CONTACT.
2	15 - 40	5GY 4/1, GREENISH-GREY MOTTLED MUDSTONE, MASSIVE, SILTY, FRIABLE, SHALEY PARTING, HORIZONTAL TREND TO MOTTLING, MED.-LARGE CALICHE NODULES NEAR BASE, CALCAREOUS, SHARP UPPER CONTACT.
3	40 - 66	5R 3/1 (RED-GREY), 2.5 YR N4/ (DARK GREY), REDDISH-GREY MOTTLED CALICHE (CALCRETE?) LAYER, MASSIVE, WELL INDURATED, SMALL TO MEDIUM CALICHE NODULES VERY COMMON, NO DISCERNABLE SEDIMENTARY STRUCTURES, BROWNISH-ORANGE WEATHERING SURFACE, VARIABLE THICKNESS, CALCAREOUS, SHARP UPPER CONTACT.
4	66 - 198	5GY 4/1, GREY SILTY MUDSTONE, PRIMARILY MASSIVE, VERY FOSSILIFEROUS, WELL INDURATED, BLOCKY PARTING, SOME REMNANT HORIZONTAL STRATIFICATION, ABUNDANT SMALL CALICHE NODULES THROUGHOUT, ESPECIALLY AT BASE, ABUNDANT FRESHWATER BIVALVES, GASTROPODS, ETC., FOSSILS ARE LARGER NEAR THE BASE OF THIS UNIT, CALCAREOUS, SHARP UPPER CONTACT.
5	198 - 215	5GY 4/1, DARK GREY SILTY MUDSTONE, MASSIVE, FRIABLE, SHALEY PARTING, NON-FOSSILIFEROUS, VERY SLIGHTLY MOTTLED, SLIGHTLY CALCAREOUS, SHARP UPPER CONTACT.

6	215 - 266	2.5YR 6/, LIGHT GREY SILTSTONE, MASSIVE, WELL SORTED, SHALEY PARTING, FRIABLE, NO ROOT CASTS, NO CALICHE NODULES, CALCAREOUS, SHARP UPPER CONTACT.
7	266 - 315	GREY SANDSTONE, POORLY SORTED, FINE-MED. GRAINED, RIPPLE CROSS-BEDDING (1 cm.) AND HORIZONTAL LAMINATIONS (<1 cm.), EXTENSIVELY BURROWED AT TOP, CALCAREOUS (5), SHARP UPPER CONTACT.
8	315 - 335	LIGHT GREY SILTSTONE, MASSIVE, FOSSILIFEROUS, CONTAINS FRESHWATER BIVALVES AND GASTROPODS, WELL INDURATED, BLOCKY PARTING, SOME REMNANT HORIZONTAL LAMINATIONS, SLIGHTLY CALCAREOUS, SHARP UPPER CONTACT.
9	335 - 343	5Y 5/2, LIGHT OLIVE-GREY SILTY MUDSTONE, MASSIVE, BLOCKY PARTING, FRIABLE, MOTTLED, "POPCORN" TEXTURED WEATHERED SURFACE, NON-CALCAREOUS, SHARP UPPER CONTACT.
10	343 - 384	5Y 3/2, OLIVE-BROWN BENTONITE, MASSIVE, EXTREMELY VARIABLE THICKNESS, WEATHERED "POPCORN" TEXTURE SURFACE, NON-CALCAREOUS, SHARP UPPER CONTACT.
11	384 - 410	DARK GREY SILTY MUDSTONE, MASSIVE, BLOCKY PARTING, FOSSILIFEROUS, ABUNDANT FRESHWATER BIVALVES AND GASTROPODS, SOME FOSSILIZED PLANT MATERIAL, A FEW SCATTERED CALICHE NODULES, SLIGHTLY CALCAREOUS, SHARP UPPER CONTACT.

12	410 - 566	GREY SANDSTONE AND SILTSTONE, ALTERNATING SANDSTONE LEDGES AND SILTSTONE SLOPES, PERCENT SANDSTONE INCREASES UPWARDS, FINE GRAINED, WELL SORTED SANDSTONE, WELL SORTED SILTSTONE, PREDOMINANTLY HORIZONTALLY LAMINATED, SOME RIPPLE SCALE (1 cm.) CROSS-STRATIFICATION, SMALL SCALE TROUGH CROSS-BEDDING (2 cm.), WEATHERED SURFACES ORANGISH RED, CALCAREOUS, SHARP UPPER CONTACT.
13	566 - 617	5GY 5/1, GREENISH-GREY SILTY MUDSTONE, MASSIVE, BLOCKY PARTING, OCCASIONAL SMALL CALICHE NODULES, CALCAREOUS, UPPER CONTACT CONCEALED.
14	617 - 781	5GY 5/1, GREENISH-GREY SILTY MUDSTONE, MASSIVE, SHALEY PARTING, SMALL-MEDIUM CALICHE NODULES THROUGHOUT, CALCAREOUS, UPPER CONTACT CONCEALED.
15	781 - 901	5GY 4/1, GREY-GREEN SILTY MUDSTONE, MASSIVE, FRIABLE, SHALEY PARTING, NON-CALCAREOUS, UPPER CONTACT CONCEALED.
16	901 - 1045	5GY 5/1, LIGHT GREY-GREEN SILTY MUDSTONE, MASSIVE, SHALEY PARTING, FOSSILIFEROUS, ABUNDANT FRESHWATER BIVALVES AND GASTROPODS, SOME FOSSIL PLANT MATERIAL, SMALL CALICHE NODULES THROUGHOUT, A FEW VERY SMALL ROOT CASTS, CALCAREOUS, SHARP UPPER CONTACT.
17	1045 - 1129	GREY SILTSTONE, MASSIVE, WELL SORTED, CALCAREOUS, SHARP UPPER CONTACT.

18	1129 - 1201	5GY 5/1, GREY-GREEN SILTY MUDSTONE, MASSIVE, FRIABLE, BLOCKY PARTING, ABUNDANT ROOT CASTS AND CALICHE NODULES, CALICHE NODULES ESPECIALLY ABUNDANT AT BASE, A WELL INDURATED 22 cm. THICK CALICHE HORIZON OCCURS AT THE BASE OF THIS UNIT, ABUNDANT PROSAURALOPHAN HADROSAUR BONES ARE FOUND THROUGHOUT THIS UNIT CALCAREOUS, SHARP UPPER CONTACT.
19	1201 - 1258	5GY 4/1, DARK GREY SILTY MUDSTONE, MASSIVE, FRIABLE, BLOCKY PARTING, A FEW ROOT CASTS AND CALICHE NODULES, NON-FOSSILIFEROUS, NON-CALCAREOUS, SHARP UPPER CONTACT.
20	1258 - 1433	GREYISH-GREEN SILTY MUDSTONE, MASSIVE, FRIABLE, BLOCKY PARTING IN LOWER REACHES OF UNIT, SHALEY PARTING IN UPPER REACHES, FOSSILIFEROUS, TINY BONE FRAGMENTS, FRESHWATER BIVALVES AND GASTROPODS, SMALL-MEDIUM CALICHE NODULES THROUGHOUT UNIT, LOWER 30 cm. OF UNIT IS SLIGHTLY SILTIER AND MORE FOSSILIFEROUS, CALCAREOUS, SHARP UPPER CONTACT.
21	1433 - 1519	GREY SANDSTONE, FINE GRAINED, WELL SORTED, MUD RIP-UPS AND/OR PEDOLITHS? AT BASE, TROUGH CROSS-BEDDING (5 cm.), EXTENSIVELY BURROWED AT TOP, WEATHERS ORANGISH-BROWN, CALCAREOUS, GRADATIONAL UPPER CONTACT.
22	1519 - 1601	5GY 4/1, GREY SILTY MUDSTONE, VERY POOR EXPOSURE, SHALEY PARTING, CALCAREOUS, SHARP UPPER CONTACT.
23	1601 - 1625	GREY SANDSTONE, VERY FINE GRAINED, WELL SORTED, RIPPLE SCALE CROSS-BEDDING (1-2 cm.), TROUGH CROSS-BEDDING (<1 cm.), PLANAR LAMINATION, WEATHERS PALE RED, CALCAREOUS, GRADATIONAL UPPER CONTACT.

24	1625 - 1761	5GY 4.5/1, DARK GREY SILTY MUDSTONE, MASSIVE, SILTIER AND BETTER INDURATED NEAR UPPER CONTACT, BLOCKY PARTING, CALCAREOUS, GRADATIONAL UPPER CONTACT.
25	1761 - 1795	LIGHT GREY-GREEN SILTSTONE, MASSIVE, POORLY SORTED, WELL INDURATED, MUDDY MATRIX, CALCAREOUS, SHARP UPPER CONTACT.
26	1795 - 2007	5GY 4/1, DARK GREY MUDSTONE, MASSIVE, WELL INDURATED AT BASE, BLOCKY PARTING, CALCAREOUS, SHARP UPPER CONTACT.
27	2007 - 2028	LIGHT GREY SILTSTONE/SILTY MUDSTONE, MASSIVE, WELL INDURATED, WELL SORTED, VERY CALCAREOUS, SHARP UPPER CONTACT.
28	2028 - 2336	GREY SANDSTONE, MEDIUM-COARSE GRAINED AT BASE, FINE GRAINED AT TOP, DIFFERENTIALLY CEMENTED, BASAL LAG CONSISTING OF SOIL CLASTS AND BONE, MEDIUM-LARGE SCALE CROSS-BEDDING AT BASE OF CHANNEL (20 cm.), SMALLER SCALE TROUGH CROSS-BEDDING AND PLANAR LAMINATIONS OCCUR UPWARDS IN UNIT, RIPPLE CROSS-LAMINATION (1-2 cm.) IS VERY COMMON IN UPPER PORTIONS OF UNIT, ORANGE-BROWN CEMENTED LEDGES ARE TYPICALLY BURROWED AND BIOTURBATED, BURROWS FREQUENTLY CONTINUE THROUGH THE INDURATED LEDGES (25-30 cm.) INTO UNDERLYING POORLY CEMENTED SAND, 3-D OUTCROP, CALCAREOUS, SHARP UPPER CONTACT.
29	2336 - 2470	5GY 4/1, DARK GREY-GREEN SILTY MUDSTONE, MASSIVE, FRIABLE, SHALEY PARTING, BETTER INDURATED AND SILTIER AT TOP, SLIGHTLY CALCAREOUS, SHARP UPPER CONTACT.
30	2470 - 2493	GREY SANDSTONE, VERY FINE GRAINED, WELL SORTED, HORIZONTAL LAMINATIONS (1 mm.), EXTENSIVELY BURROWED, RED-BROWN WHEN WEATHERED, CALCAREOUS, TOP OF BUTTE.

APPENDIX #2

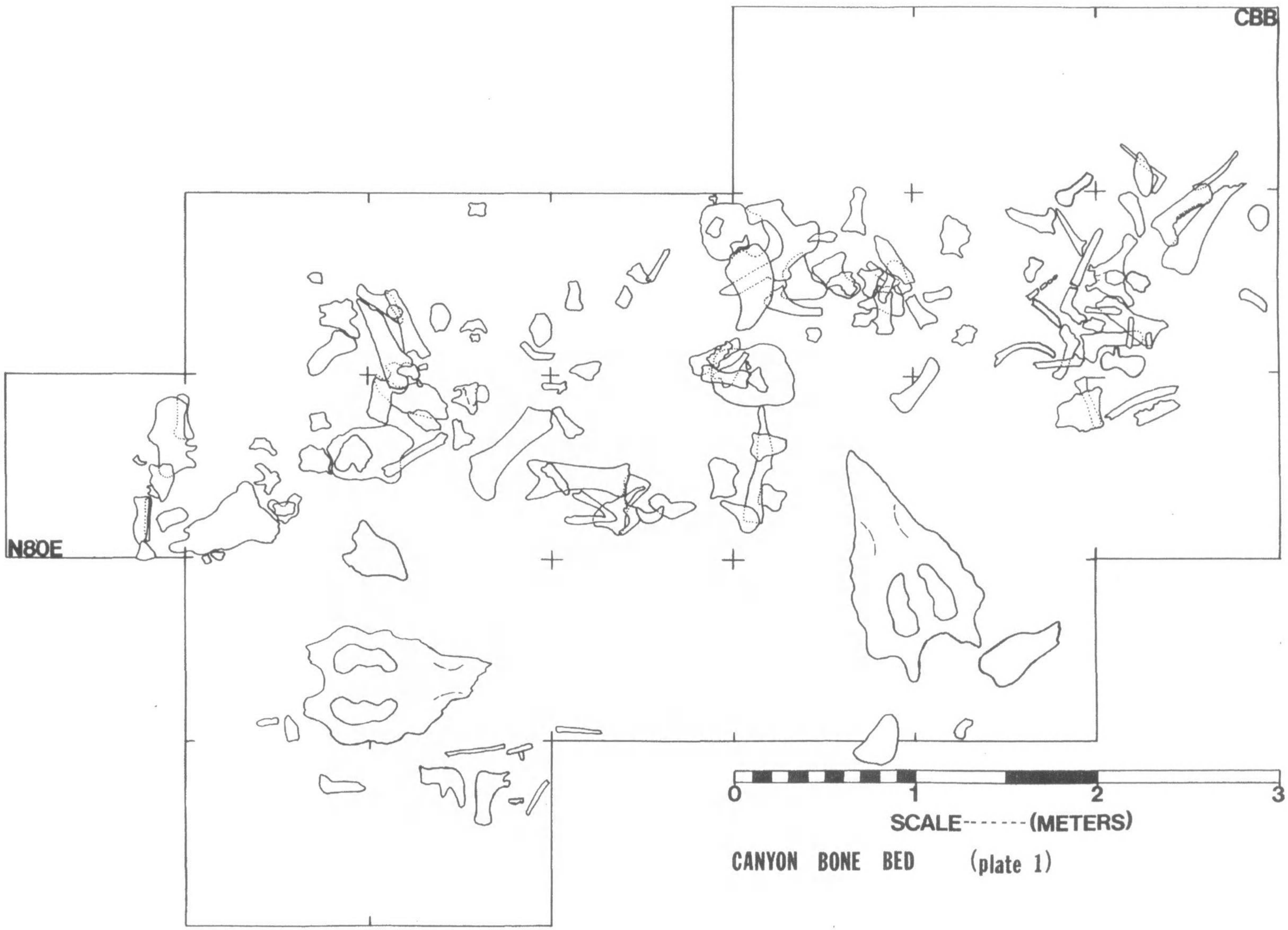
BONE BED COMPOSITION AND BONE BED MAPS

TABLE 1

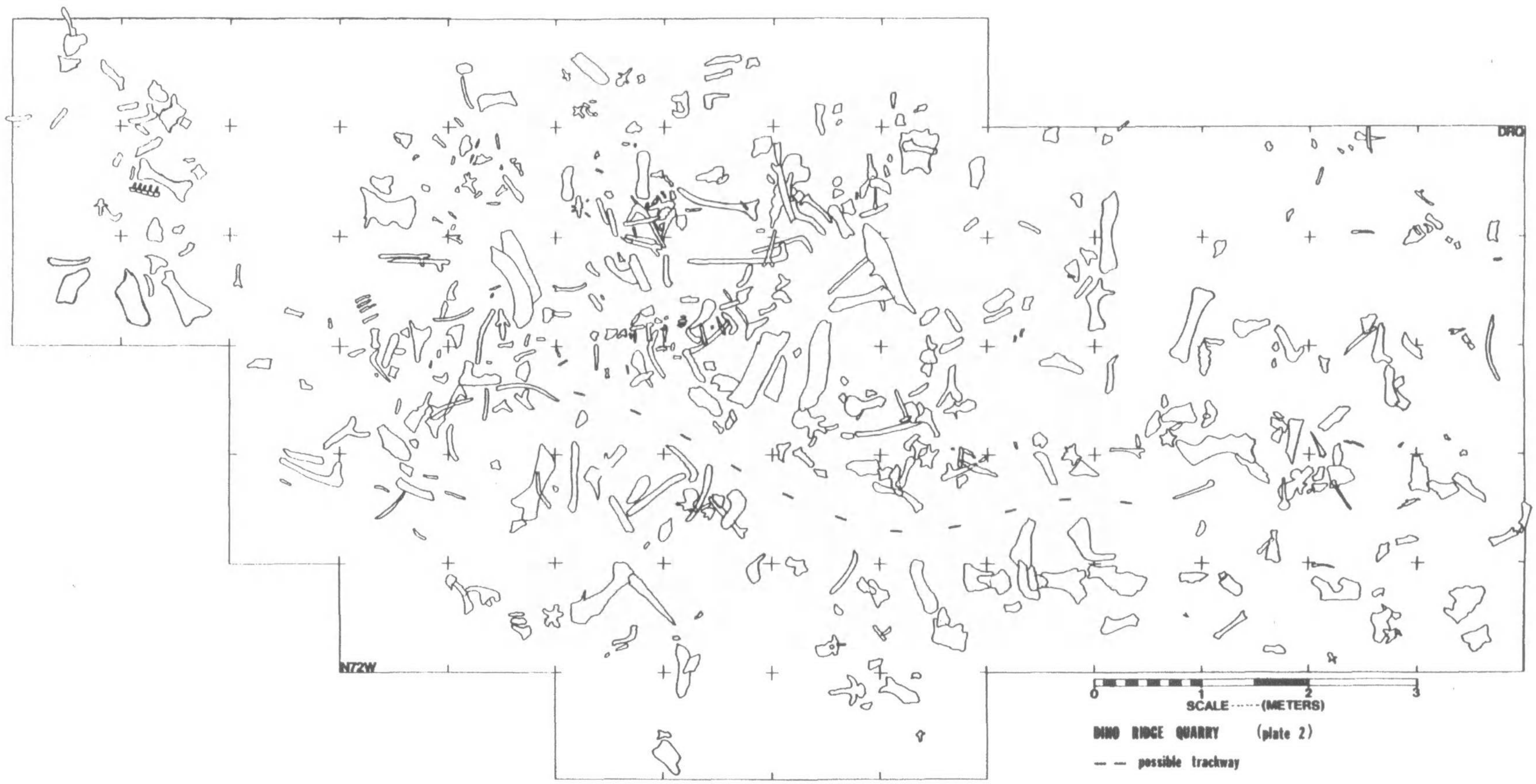
LIST OF SKELETAL ELEMENTS: CANYON BONE BED, DINO RIDGE QUARRY, WESTSIDE QUARRY

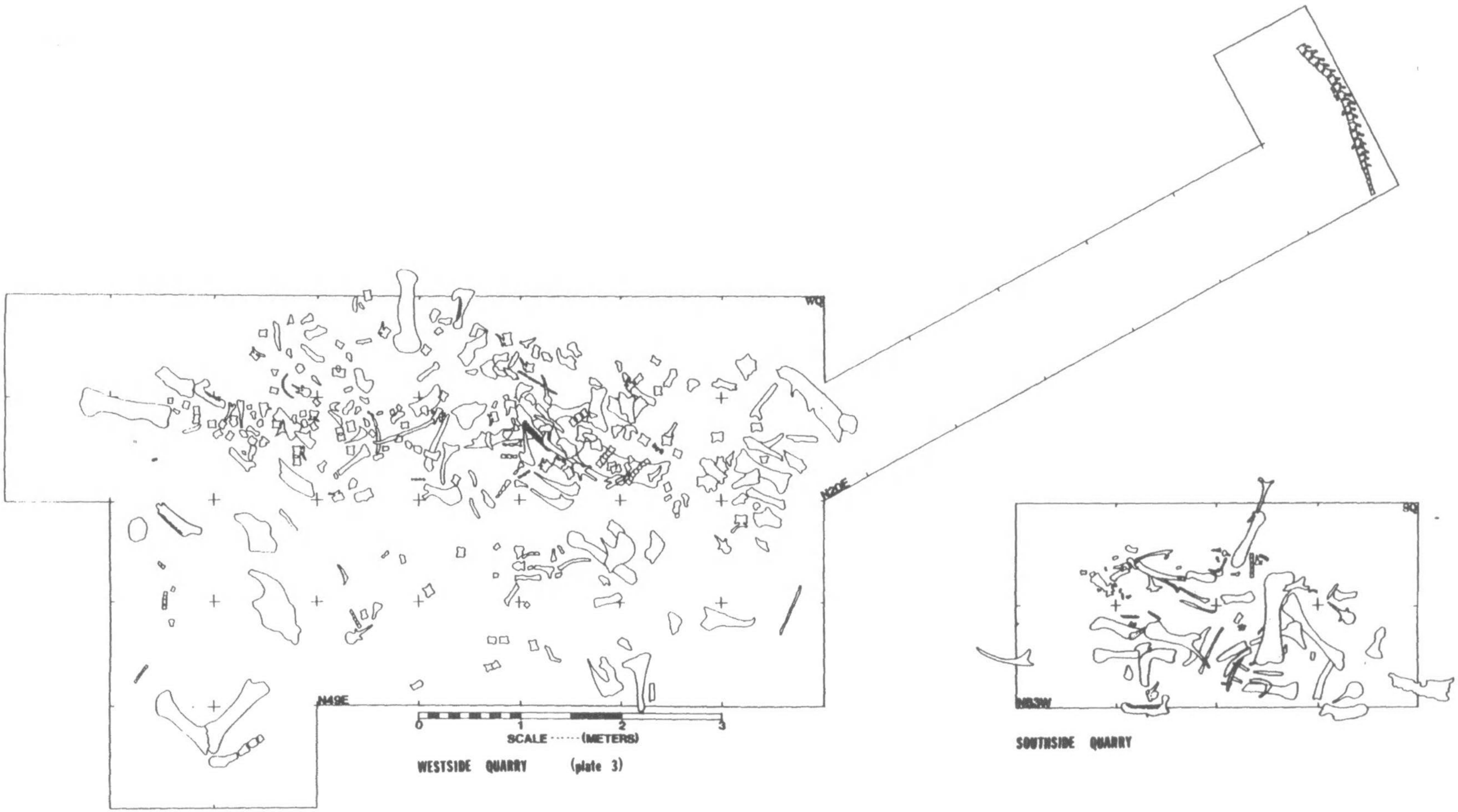
	NUMBER REPRESENTED IN SAMPLE		
BONE BED---	CBB	DRQ	WQ
MOR #---	(MOR 456)	(MOR 373)	(MOR 447 & 454)
SKELETAL ELEMENT			
VERTEBRAE	10	37	66 (61 art.)
NEURAL ARCHES	3	19	24
CHEVRONS	0	0	9
RIBS	16	25	25
PHALANGES	10	3	49
METAPODIALS	6	3(1)	15
RADII	1	0	4
ULNAE	1	0	1
FIBULAE	0	2	3
CORACOIDS	1	1	2
SCAPULAE	6	4(1)	3
HUMERI	2	2	2
FEMORA	3	2(1)	3
TIBIAE	5	3	4
SACRALS	0	3	1
STERNALS	0	1	3
ILIA	2	8	3
ISCHIA	0	2	2
PUBI	3	4	2
COMPLETE SKULLS	2	0	0
DISARTICULATED CRANIAL ELEMENTS	61	83(6)	75
RAMI	7	6(1)	8
UNIDENTIFIED FRAGMENTS	19	23	23
TOTAL*	157	288	388

*Totals reflect bones prepared and curated in the Museum of the Rockies collection as of January, 1989.



CANYON BONE BED (plate 1)


DRO
N72W
0 1 2 3
SCALE······(METERS)
DINO RIDGE QUARRY (plate 2)
— — possible trackway


WQ
N20E
N49E
SQ
N83W
0
1
2
3
SCALE ······ (METERS)
WESTSIDE QUARRY (plate 3)
SOUTHSIDE QUARRY